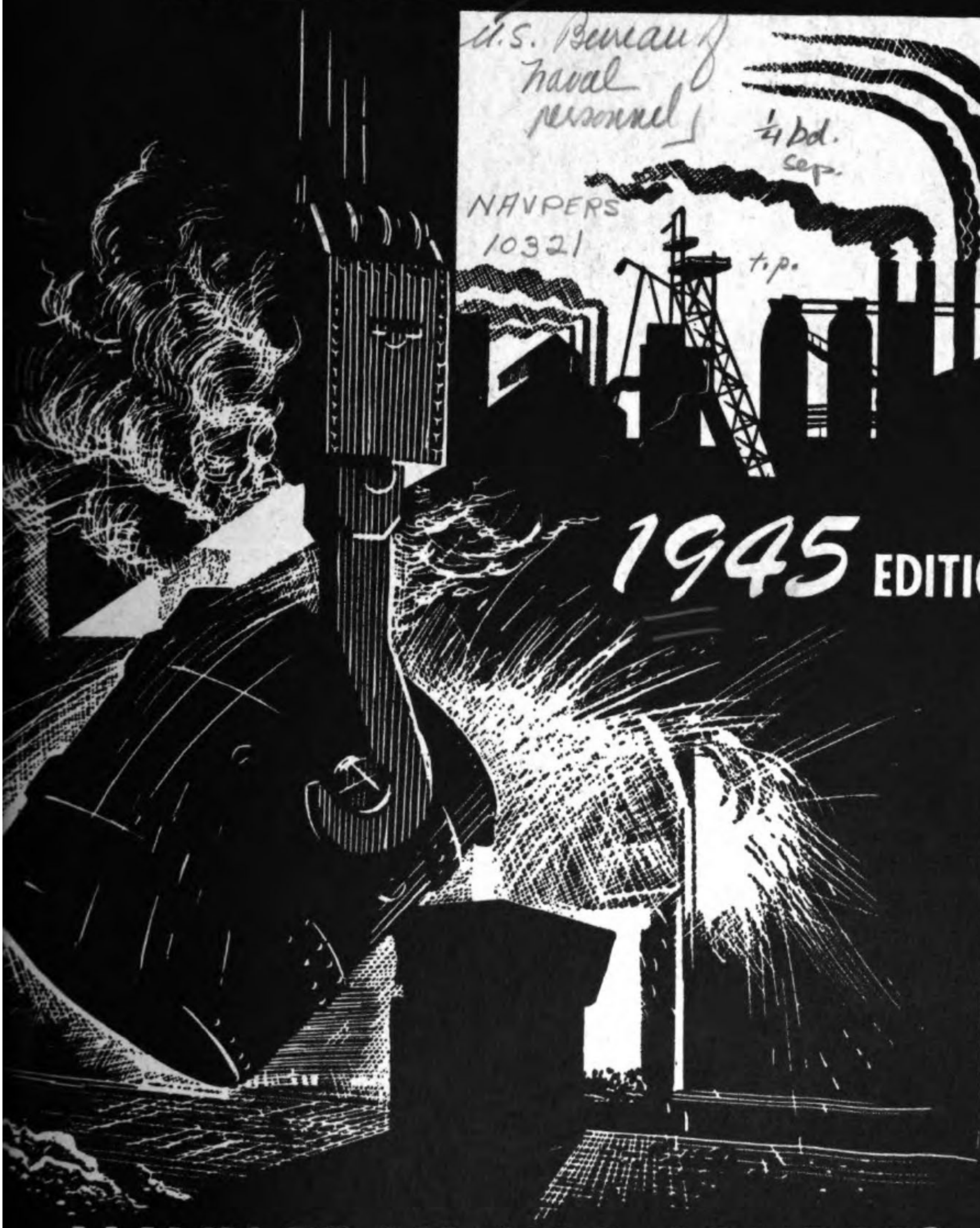
Aircraft
METALS



U.S. Bureau of Naval Personnel
1/4 bd. sep.
NAVPERS 10321
t.p.

1945 EDITIO

NAVY TRAINING COURSES

AIRCRAFT METALS

PREPARED BY
STANDARDS AND CURRICULUM DIVISION
TRAINING
BUREAU OF NAVAL PERSONNEL

NAVY TRAINING COURSES
EDITION OF 1945

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON: 1945

For Sale by the Superintendent of Documents, Washington, D. C.

PREFACE

This book is written for the enlisted men of Naval Aviation. It is one of a series of books designed to give them the necessary information to perform their aviation duties.

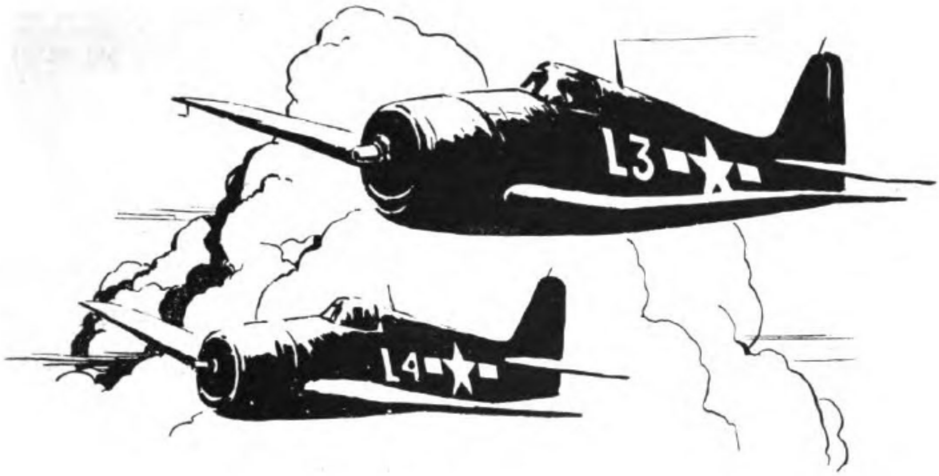
A knowledge of aircraft metals is of primary importance to Aviation Metalsmiths. Their concern is metal work as it relates to airplane structures. It is well for them to start their careers with a background of information about the metals they will meet every day in their experience. They should know the characteristics of aircraft metals and the best practices for using such metals.

Iron, although not classed as an aircraft metal, is discussed briefly because the Aviation Metalsmith will have to work with it in maintenance and repair work around the shop. This is followed by explanations of steel and non-ferrous metals and their alloys which are now being used. Following this are descriptions of heat treating, hot and cold working processes, and protection for metals. A section on the physical testing of aircraft metals completes the text.

As one of the NAVY TRAINING COURSES, this book represents the joint endeavor of the Training Courses Section of the Bureau of Naval Personnel, and the Naval Air Technical Training Command.

TABLE OF CONTENTS

AIRCRAFT METALS



CHAPTER 1

WHY METALS?

IRON MEN AND IRON SHIPS

MEN OF IRON HAVE MANNED THE NAVY'S SHIPS EVER SINCE THE DAYS OF JOHN PAUL JONES—men like Captain "Mike" Moran and his crew aboard the *Boise*. Captain Moran is a hard-hitting, two-fisted Irishman, and no man's understudy. When advised that five Jap ships were bearing down on them, he issued his famous command—"Pick out the biggest and commence firing." In a flat 27 minutes the crew of the *Boise* had sunk them all—actually six ships instead of five.

Iron ships, however, are less than a century old. The first iron-clad, the *Monitor,* won what has been called "the most decisive engagement ever fought between two vessels." When she cornered and defeated the *Merrimac* in the harbor at Hampton Roads, SHE CONCLUSIVELY ESTABLISHED ONCE AND FOR ALL, THE SUPERIORITY OF METAL SHIPS. Then began a new era in shipbuilding and the Navy found need for the metalsmith.

Today, metal ships fly as well as float. And today, men of iron are manning these modern warplanes—men like Cmdr. David McCampbell who at war's end

had some three dozen Jap planes to his credit, and who had distinguished himself and Naval Aviation in metal ships of the air over the Pacific Ocean.

KNOW YOUR STRENGTHS

Airplanes have brought new kinds of uses to new kinds of metals. You have iron, steel, aluminum, copper, and "57 varieties" of each. One way or another, you'll find every airplane making use of them all.

Fuselages, wings, tail surfaces, ribs, and skin of airplanes are made almost entirely of SHEET METAL. To work on them you have to know sheet metal. But you have to know more than just the metals by sight and name. You MUST know how to MAINTAIN THE STRUCTURAL STRENGTH OF THE AIRPLANE you are repairing.

You have to know what is expected of the various structures of an airplane. Only then can you repair aircraft intelligently. And Naval Aviation can't use you unless you can do an intelligent repair job.

STRESS

Understanding the basic principles of airplane structures depends primarily on knowing WHAT STRESSES a member of an airplane carries.

The five basic stresses which any airplane structure may be required to withstand are TENSION, COMPRESSION, TORSION, SHEAR, or BENDING.

In figure 1(A) you see two men testing their strength in a tug of war. By pulling, they are applying a load (force) to the rope and subjecting it to stress. Stress is the resistance to being pulled apart which is developed in the rope, or in a part of an airplane under a similar load. It is measured in terms of force per unit area. Force is expressed in this country in pounds and the unit of area in square inches or fractions of a square inch. If the cross-sectional area

of the rope is ½ square inch, and the force being exerted is 300 pounds, the stress of the rope is 600 pounds per square inch (psi).

The force exerted on the rope sets up a stress known as TENSION. This tension caused by the pulling or separating force might become so great that the rope would break.

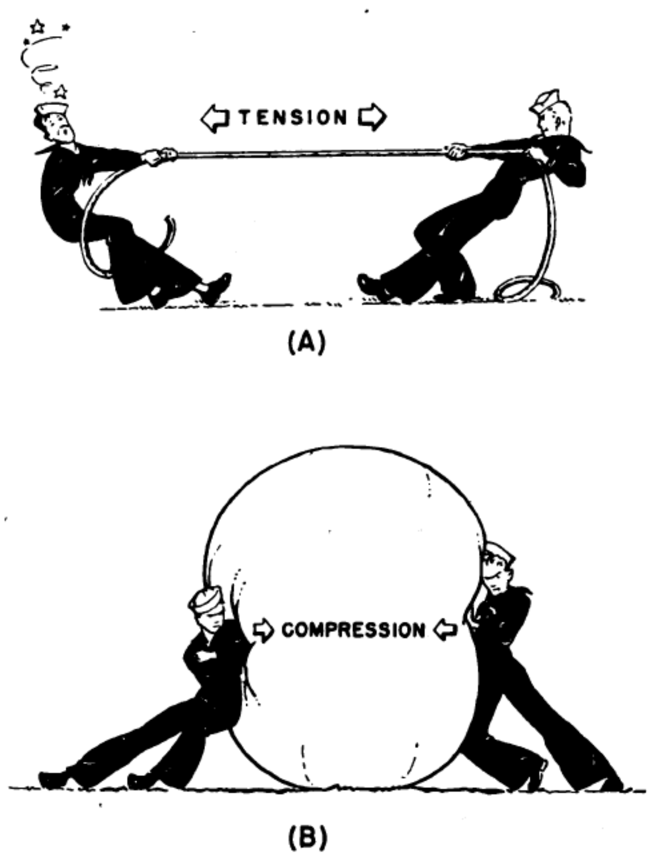


Figure 1.—Tension and compression.

The opposite type of stress, which is produced by a force tending to shorten a rigid member, is called COMPRESSION. The men you see in figure 1(B) are subjecting the push ball to compression force. The landing gear on an airplane is also subjected to compressive force when the airplane is standing on the ground.

A third type of stress is illustrated in figure 2. Here the man is subjecting the tree to BENDING. The

bending force which the man is applying causes compression on the side of the tree toward him and tension on the side away from him.

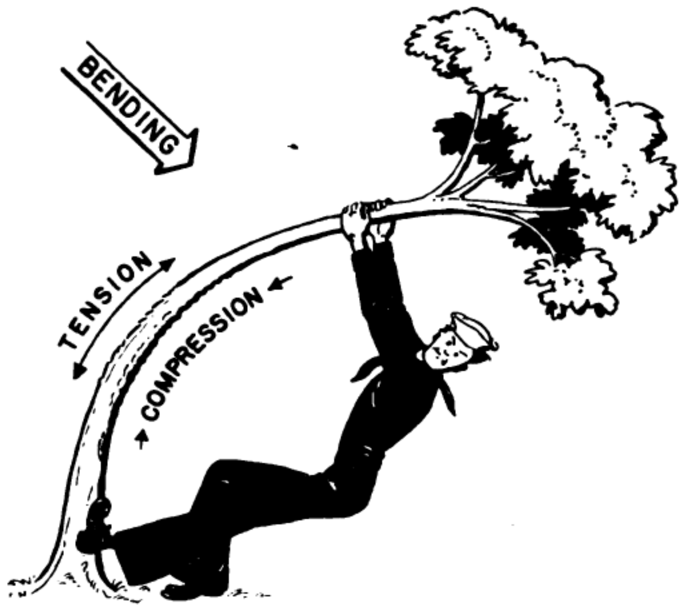


Figure 2.—Bending.

The fourth type of stress, TORSION, is illustrated in figure 3(A). When you wring out your clothes you are applying a twisting force to the cloth. This twisting force creates a stress in the cloth known as torsion.

When you cut a piece of sheet metal as the man is doing in figure 3(B), you are subjecting the metal, which is in contact with the shears, to a force known as SHEAR.

A SHELL IS STRONG

Almost all thin sheet metal structures in modern warplanes are practical adaptations of the theory of monocoque structure. Such a structure is essentially a thin-walled tubular SHELL, which although relatively light, is capable of supporting any combination of

these basic stresses. Its design, of course, determines which of these stresses and how much of them it can carry.

You can prove for yourself how efficient a true monocoque structure is. Take a can of beans. After you've eaten the beans, stand the can on end on the floor, put a board across the top and corral a number of your friends to stand on the board.

The thin wall of the can CARRIES THE ENTIRE LOAD. On the other hand, you know that you alone can crush a tin can if you lay it on its SIDE and step on

TORSION (A) SHEAR (B)

Figure 3.—Torsion and shear.

it. Or, by exerting a little pressure, you can even crush it between your hands.

The moral of this experiment is that a monocoque structure, even though made of thin metal is capable of bearing up under great loads. There is, however, a catch. These loads can be supported only IF THE TRUE SHAPE OF THE STRUCTURE CAN BE MAINTAINED. Most airplane structures are SEMI-MONOCOQUE rather than monocoque, because it is difficult to maintain the true shape of a monocoque structure.

HOLES AND SLITS

If you should cut a HOLE in a monocoque tube made of paper like those in figure 7, you would decrease its strength. The amount of decrease would depend upon the amount of MATERIAL REMOVED and the SHAPE OF THE HOLE. You would have set up a weak point where loading stresses could spoil the tube's true shape.

BUT if you glued a CARDBOARD RIM around the hole, you could put back the strength you had taken away by cutting the hole. The wider and thicker the cardboard rim, the stronger is the reinforcement.

The same thing applies to handholes, windows and doors cut into a monocoque airplane fuselage. They MUST be reinforced. Sometimes on a repair job, you may find you have to cut a hole in a structure to get at the inside.

Assuming that you understand the structural requirements for the particular job at hand, you can cut a handhole. Then when you have finished the job, cut a frame of thicker metal to encircle the hole, and thus preserve the monocoque structure. To cover the hole, attach a cover plate to the reinforcing frame.

Now, if you SPLIT a monocoque tube lengthwise, it loses its TORSIONAL STRENGTH. The CIRCUMFERENCE OF ANY CROSS SECTION of a monocoque aircraft structure MUST BE CONTINUOUS. Obviously, if such a structure is split, there is a GAP in the circumference. Take, for example, a monocoque engine nacelle, in which the bottom is cut out to make room for the retracted wheel. Here you have a gap in the circumference of the structure which requires SPECIAL BRACING if it is to keep its torsional strength. You must build in a bracing structure, like a patch, across the gap.

THE THEORY BEHIND SHELL STRENGTH

In a monocoque structure it is possible to increase the strength of the tubular shell in proportion to—

INCREASE IN DIAMETER of the structure.

DECREASE IN WALL THICKNESS of the structure.

Figure 4 shows two tubes, one thin-walled, the other thick-walled. Both (*A*) and (*B*) of figure 4 are of the same material, length and weight. The radius of (*A*) however is TWICE that of (*B*) and the wall thickness of (*A*) is HALF that of (*B*).

Yet tube (*A*), with double the radius of curvature and half the wall-thickness can carry FOUR TIMES THE LOAD in compression, bending and torsion. It is also

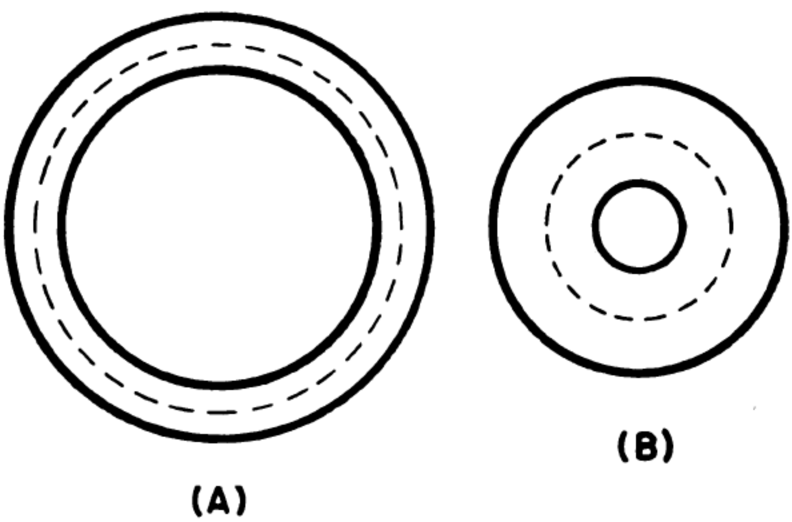


Figure 4.—Thin and thick-walled tubes.

four times as RIGID under bending or torsional stresses.

This rigidity, as distinguished from strength, is in itself an important consideration in designing an airplane. The greater the rigidity of a fuselage, for example, the less danger there is that it might bend or twist and thus upset the balance of the stresses within it.

But, you ask, isn't there any LIMIT to the process of increasing the diameter and decreasing the wall thickness of metal tube, thus increasing the load-carrying strength while maintaining the original weight? Yes, there is. The limit is reached when you arrive at the point where wrinkling and buckling of the thin metal occurs. What happens is this—

When you reach that limit, the walls of the tube are thin. If you exceed the limit by making the walls still thinner, they will become UNSTABLE. The result of such instability is wrinkling or buckling of the tube walls.

BUCKLING is a form of instability of the entire MEMBER of a structure. WRINKLING is a LOCAL condition of instability. The larger the radius of curvature becomes and the thinner the sheet becomes, the LESS will be the load which a tube can bear without wrinkling.

It is often hard to tell which type of failure occurred first in a member—wrinkling or buckling—because

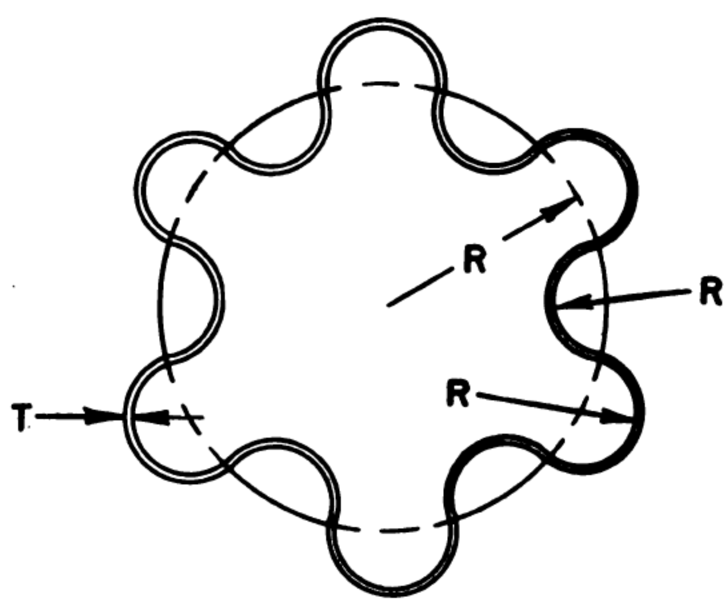


Figure 5.—A thin-walled tube is corrugated.

one can lead to the other. For this reason, engineers attempt to design a member so that it has equal resistance to both types of failure. One way to increase the resistance of a member to wrinkling is to corrugate it, as in figure 5.

The GOVERNING radius of curvature, *R*, is small and therefore the tube resists wrinkling. But the PRINCIPAL radius of curvature, *R*, is large while the wall-thickness,

T, is small. Therefore the strength and weight advantages of a thin-wall tube are preserved.

BUT such a corrugated tube would tend to fold up under torsional stress. Thus you have to add stiffening devices—figure 6 shows one of the most common variations of the idea of corrugation, a thin-walled tube with stringers.

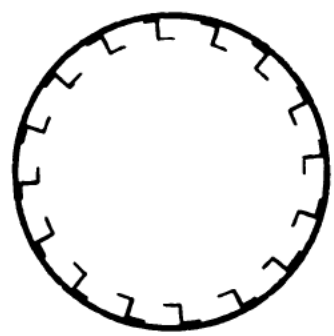


Figure 6.—Thin-walled tube with stringers.

Here the thin outer shell and the strips of reinforcing metal (stringers) form a mutually supporting unit. The stringers act as a kind of corrugation and thus enable the thin wall of the shell to resist wrinkling that would otherwise be present.

THE SKIN CARRIES SHEAR LOADS

Shear loads in a semi-monocoque airplane structure are generally carried by the thin, sheet-metal skin. The designers figure that some wrinkling will occur in the skin even under loading which is LESS THAN HALF the structure's design load. But these wrinkles are not permanent and go away as soon as the load is removed, if the structure hasn't been overstressed.

WATCH OUT FOR PERMANENT WRINKLES. If these kinks DON'T disappear, it usually means failure in some other part of the structure—and a repair job for YOU.

BULKHEADS CARRY CONCENTRATED LOADS

Thin-walled monocoque structures in an airplane are no good at all unless their true cylindrical shape is maintained. This is done by means of BULKHEADS and REINFORCING RINGS, which guard against wrinkling and denting of the skin when concentrated loads are applied.

Figure 7 shows what happens to the skin as a result of such loads.

TENSION is not shown because it is not a serious

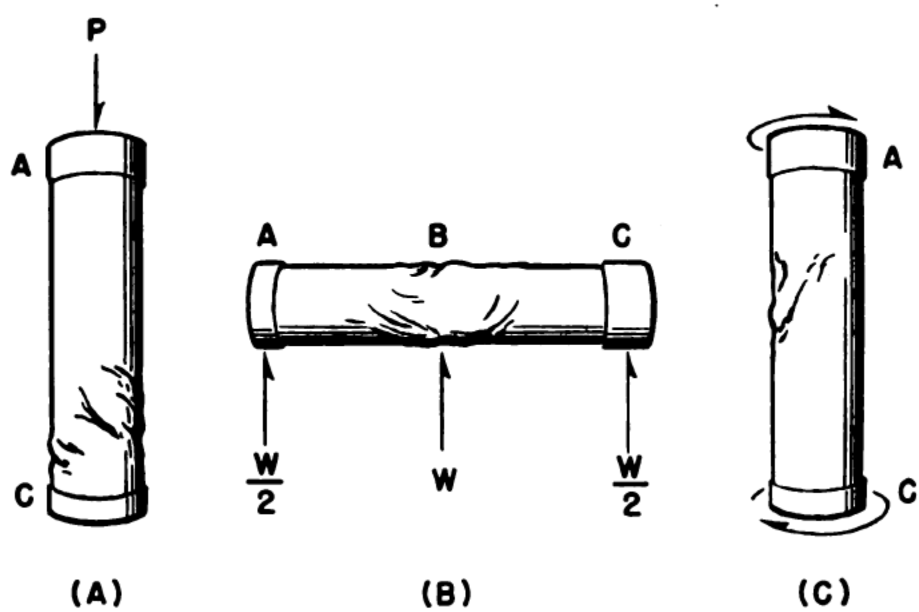


Figure 7.—It's got wrinkles.

problem in monocoque structures. The designer who makes a monocoque structure strong enough to withstand compression, bending and torsion, AUTOMATICALLY takes care of tension.

Figure 7 (*A*) shows a paper monocoque tube carrying a COMPRESSION LOAD, (*B*), a BENDING load and (*C*), a TORSION load such as exists in the torque tube of an aileron or elevator.

In (*A*) you see how the skin wrinkles when under compression because there are no blocks or bulkheads between *A* and *C*.

In (*B*) a center block or bulkhead has been added which distributes somewhat the bending load. But the skin still wrinkles. Probably if there were more bulkheads between *A* and *C* instead of only one, the wrinkling you see in (*B*) would not have occurred.

The wrinkling in (*C*) under TORSIONAL stress probably would also not have occurred if bulkheads had been inserted between *A* and *C*.

Structures which perform the functions of blocks *A, B,* and *C,* in figure 7 are called BULKHEADS. BULKHEADS and REINFORCING RINGS are the chief means which designers use to get around wrinkling and hence local failures due to concentrated loads. These devices RECEIVE the CONCENTRATED LOADS and DISTRIBUTE THEM evenly into the thin walls of the structure.

WARNING—

> When you repair a monocoque structure you MUST avoid concentrated loads at points which might lead to local failure.

PRACTICAL STUFF

Bulkheads and reinforcing rings are used, for instance, on such monocoque structures as WINGS, FUSELAGE, ENGINE NACELLES and CONTROL SURFACES. (If the wings and control surfaces are not themselves tubes, they are built around tubes.)

Look at figure 8. Here you see the part bulkheads and reinforcing rings play in the ATTACHMENT OF A FUSELAGE TO A WING.

With a fuselage and a wing, you have essentially two tubes at right angles to each other. In (*A*) of figure 8, which shows the arrangement on a low-wing airplane, you see that the wing beam has bulkheads *a-a* to strengthen the points where it is attached to the fuselage. The fuselage reinforcing rings *b-b* are attached to these bulkheads.

In (*B*), the arrangement for a mid-wing airplane, you see the set-up where the wing passes through the

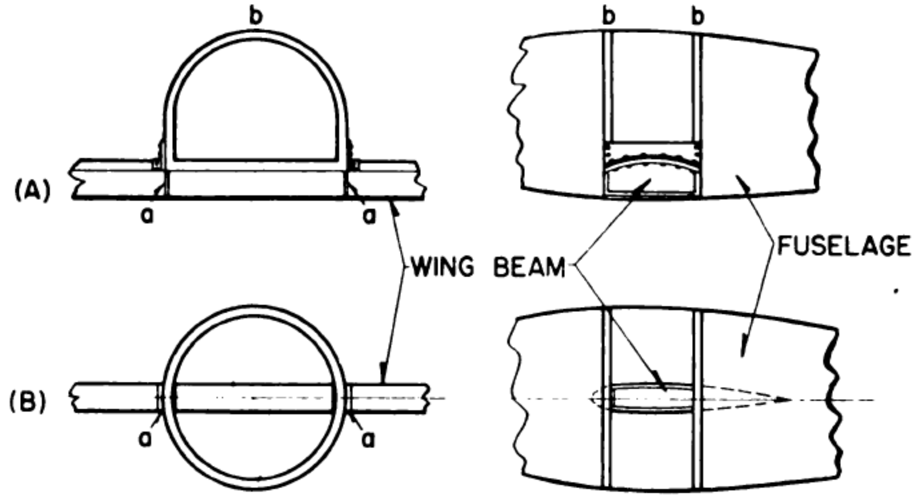


Figure 8.—Fuselage—wing connection.

center of the fuselage. In the drawing at the left in (*B*), you see the wing beam passing through the fuselage.

Figure 9 shows the way bulkheads are used in ATTACHING AN ENGINE MOUNT to an ENGINE NACELLE or to a MONOCOQUE FUSELAGE.

A bulkhead is fitted, as in figure 9, into the end of the nacelle or fuselage and the fittings for the engine mount are attached to this bulkhead. The skin around the bulkhead is often reinforced for a few inches by a thicker skin to further distribute the loads and prevent local failures where the stresses may be concentrated.

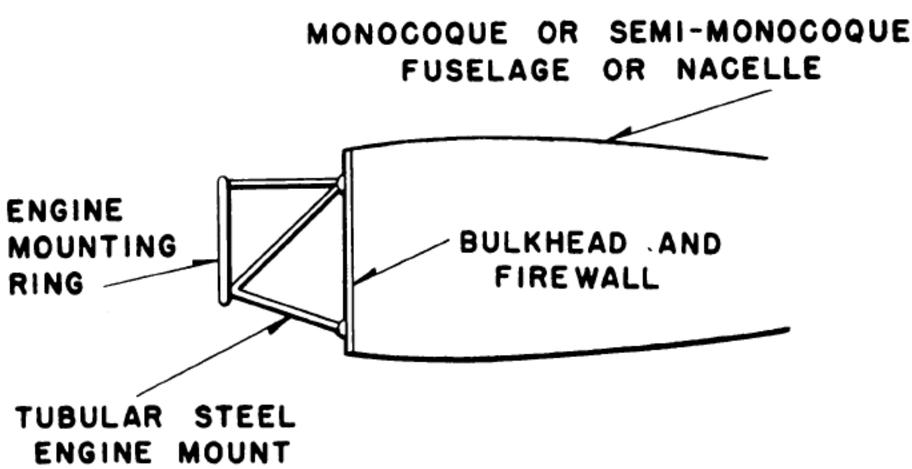


Figure 9.—Attachment of engine mount.

The fundamental idea for ATTACHING A STABILIZER OR VERTICAL FIN TO THE FUSELAGE is shown in figure 10.

Here, the bulkhead is an integral part of the fuselage. Its job is to strengthen the open end of the monocoque fuselage and to carry the fittings to which the spars of the tail assembly parts are attached.

Bulkheads and reinforcing rings should be RIGID ENOUGH TO CARRY THE CONCENTRATED LOADS WITH A MINIMUM OF DEFORMATION. The true shape of a monocoque structure must be kept in order to develop its strength. Anything that happens to distort its skin establishes a point of weakness. THIS IS THE PRINCIPAL FACT YOU MUST KEEP IN MIND IN REPAIRING A BULKHEAD OR REINFORCING RING.

STRINGERS CARRY COMPRESSION

When you start dealing with STRINGERS you are no longer talking about a true monocoque structure. Aircraft parts which are reinforced by stiffening devices which actually help the skin carry the load, and which are not simply a means of maintaining the true shape of the skin, are SEMI-MONOCOQUE structures.

Stringers carry both COMPRESSIVE and TENSILE loads. Tensile loads, however, are usually only a small fraction of the tensile strength of the metal. Practically the entire problem consists in stiffening the structure against compression. Thin sheet metal for large diameters will carry only a SMALL compressive load without wrinkling. The idea of corrugating a tube to increase its resistance to wrinkling, shown in figure 5, is the basis for using stringers. This scheme, which makes use of the advantages obtained by corrugating thin sheet metal, yet enables the structure to keep its smooth outside surface, is accomplished by riveting strips of corrugation (stringers) to the INSIDE of the skin as in figure 6.

When a stringer and curved-sheet combination like that in the fuselage is used, the stringers usually carry

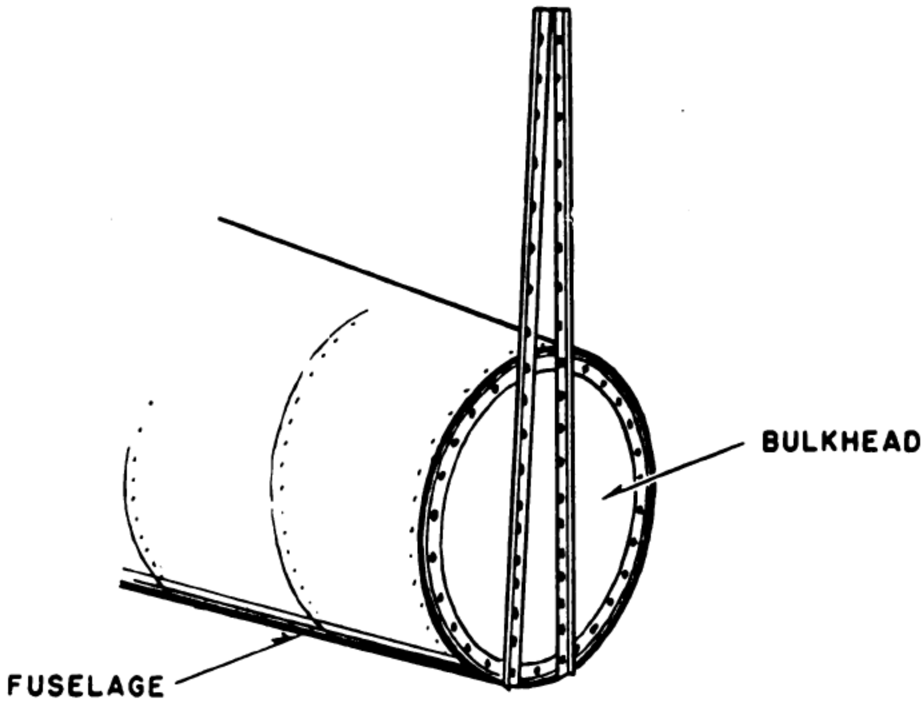


Figure 10.—Vertical fin attached to fuselage.

the major portion of the load and the skin supports and stiffens the entire structure.

Figure 11 shows some typical stringer shapes.

When stringers FAIL, they WRINKLE LOCALLY because an excessive compressive load has been imposed on them. Therefore, when you repair a stringer you must do it so that local wrinkling is prevented.

For aluminum-alloy materials used as stringers and

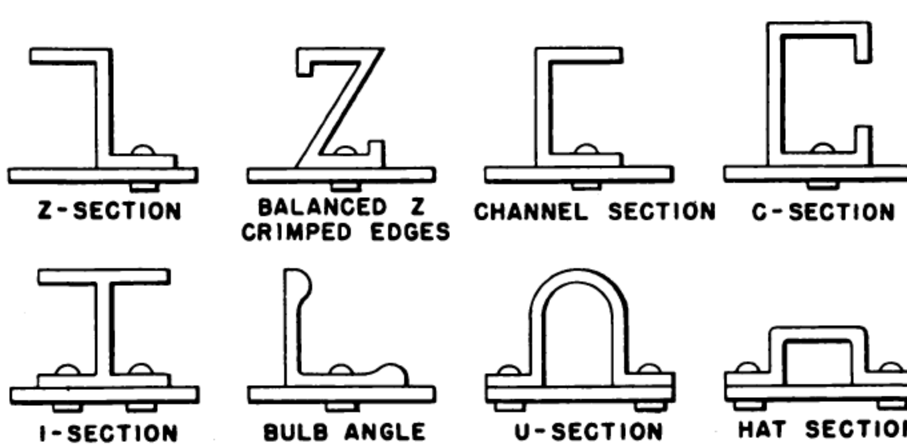


Figure 11.—Typical stringers.

skin, the UPPER LIMIT of the allowable stress for stringers is 40,000 pounds per square inch. Repairs made on this basis will have the necessary strength. When you are calculating the required strength of a repaired stringer, however, you must take into account the fact that the SKIN NEARBY MUST BE CONSIDERED WITH THE STRINGER. To be on the safe side, you should consider the skin on each side HALF-WAY TO THE NEXT STRINGER, as part of the stringer you are repairing.

ENGINE MOUNTS HAVE A TURNING MOVEMENT

There is some twisting movement in the engine mount structure. For this reason, you must be careful not to clamp the COWLING too tightly to the structure. Most cowlings used with air-cooled engines consist of a formed, thin, sheet-metal ringer shell, reinforced at points of concentrated stress. If you forgot to MAKE ALLOWANCE IN THE COWL FASTENINGS for this twisting movement of the engine mounts, you would have a rather rigid assembly and cracks might appear.

Strains set up in the nacelle structure by the vibration of the engine would soon cause the nacelle skin to crack. To relieve these stresses, the engine mount is usually set in rubber.

THE BEAM IDEA

BENDING and TORSION are the governing loads to which airplane wings are subjected. To carry these loads, a wing acts like a BEAM in supporting an airplane in flight.

Suppose you had a common beam with one end cemented in concrete as in (*A*) of figure 12. Bending is a combination of TENSION, COMPRESSION and SHEAR. If you put a load on the protruding end of the beam, it would tend to bend the beam downward. As the beam bent, the stresses set up within it would be the following.

TENSION in the UPPER FLANGE.
COMPRESSION in the LOWER FLANGE.
SHEAR in the WEB.

The web is the portion between the flanges. The point in the central part of the web which is the dividing line between tensile and compressive stresses is called the NEUTRAL AXIS. It is here that the shear

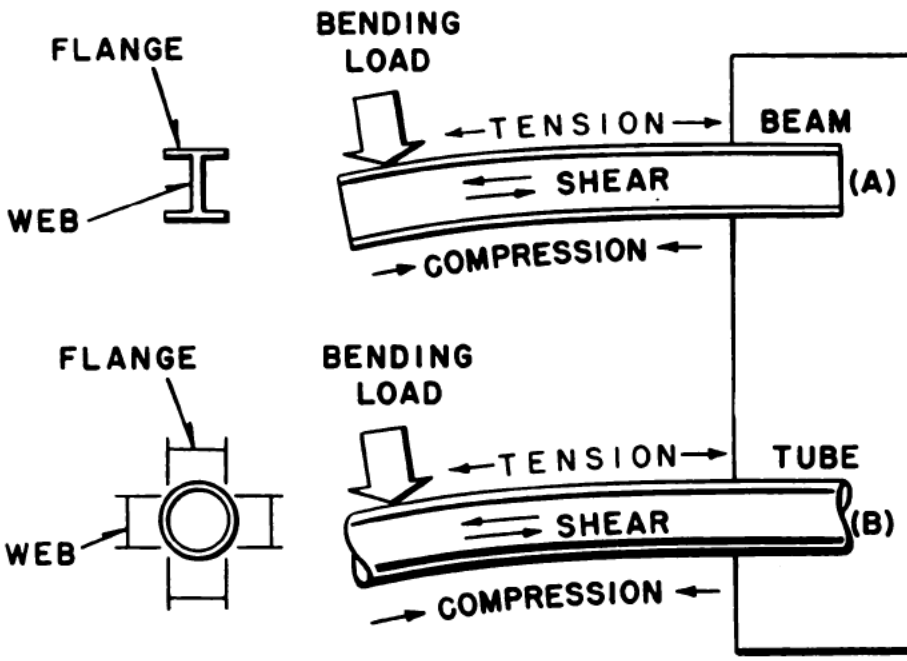


Figure 12.—The beam principle.

stress is the greatest. The resistance of the web to BENDING increases with WIDTH of the web. The resistance of the web to wrinkling under compressive stress increases with the THICKNESS of the web.

In thin, sheet-metal structure, the web carries NO COMPRESSIVE STRESS — and VERY LITTLE TENSILE STRESS. It is generally assumed to carry ONLY SHEAR.

THIN SHEET-METAL WINGS

Some wings are in use today which closely approximate the true monocoque form and depend upon the strength of the thin metal skin to carry the major

part of the wing loads. In these, only minimum stiffening devices are put in to help the wing keep its true shape and to distribute the concentrated loads. But most thin sheet metal wings are of semi-monocoque construction because it is easier to add necessary strength to the structure. In both monocoque and semi-monocoque wing structures, the air produces a LIFT or upward pressure on the wing which sets up BENDING stresses in the wing. This lift causes compression on the top and tension on the bottom of the wing as in figure 13.

In addition, the CENTER OF PRESSURE—the dot in the upper drawing of figure 13—SHIFTS across the wing chord from leading edge to trailing edge depending

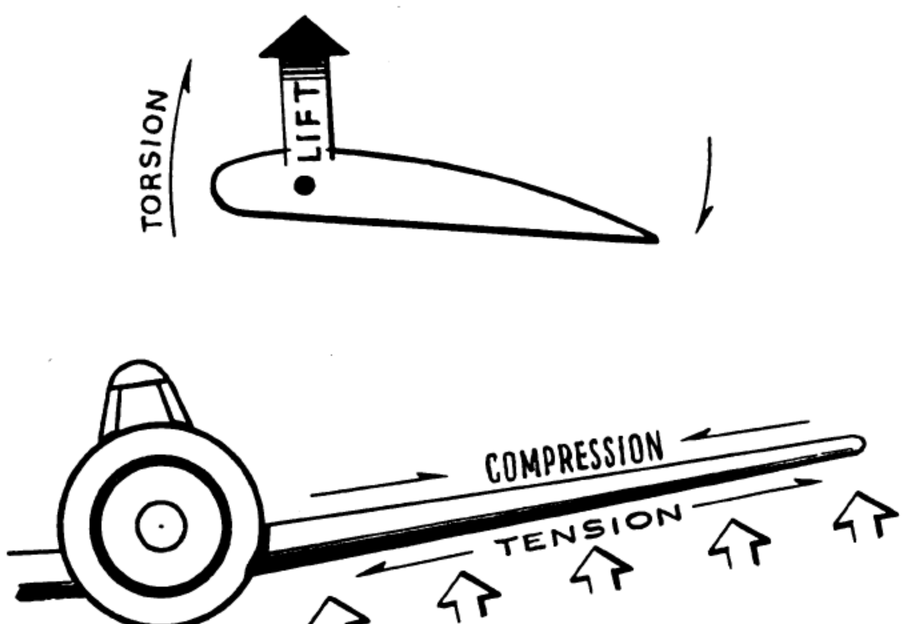


Figure 13.—What lift does to a wing.

on whether the airplane is climbing, descending, or on level flight. This shift of the center of pressure together with the raising or lowering of the ailerons, sets up TORSION stresses in the wing structure.

Thus you can see how both bending and torsion are factors which must be considered in designing aircraft wings.

There are lots of different wing constructions—as many, in fact, as there are companies which build aircraft. The following are some of the basic structures used in designing wings for the Navy.

TRUSSED WING BEAM

A trussed wing spar such as that in figure 14 is basically a beam. But its web—the central portion connecting the heavier members which form the flanges

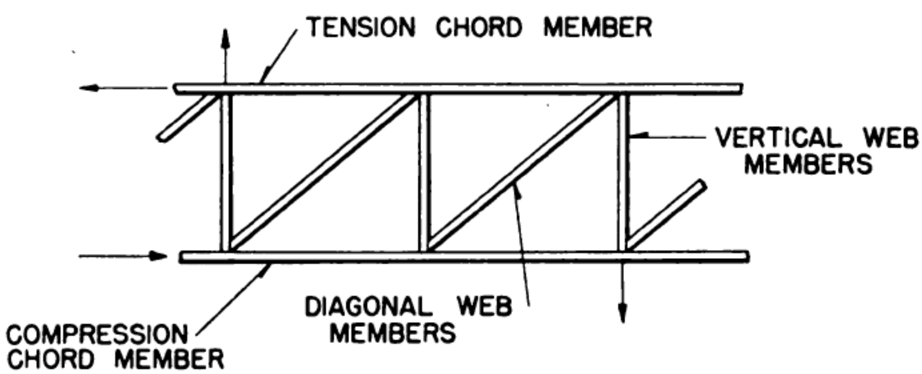


Figure 14.—A trussed wing spar.

—is not solid as in a beam. Instead a trussed wing spar has VERTICAL and DIAGONAL web members which take over the function of a solid web.

In such a trussed wing spar the flanges of the beam are called CHORD MEMBERS. With the load applied upward as it is in normal flight, the DIAGONAL web members of figure 14 are in TENSION and the VERTICAL web members, are in COMPRESSION. If the load is reversed and applied downward then the diagonal would be in compression and verticals would be in tension.

That's not just theory. A wing beam such as this trussed spar is subjected to BOTH up and down loads depending upon its position in the air or on the ground. Consequently each vertical or diagonal web member is designed to carry both tension and compression.

Metal GUSSET PLATES are inserted in the joints of a trussed beam (where chord, diagonal, and vertical members meet) to provide space for riveting these members where they intersect. A gusset plate obviously must carry the same loads as those of the three members which are riveted to it—that is, the same amounts of tension and compression. Therefore THE SHEAR STRENGTH OF THE RIVETS JOINING SUCH MEMBERS MUST BE GREAT ENOUGH TO CARRY THE TENSION AND COMPRESSION LOADS (in those members).

THIN-WEB WING BEAM

In stressed-skin wings, you usually find wing spars with THIN WEBS reinforced by vertical members like the middle drawing in figure 15.

The web, of course, carries the shear stresses between the tension and compression loads carried by the flanges of the beam.

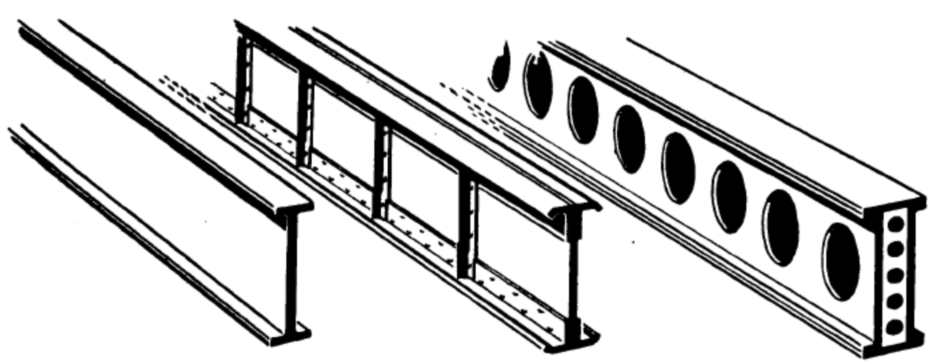


Figure 15.—Wing spars.

Designers assume that a thin web will wrinkle to some extent under any load, and the webs are designed to take that into account. Such a beam with a thin web is quite strong WHEN it is in good condition. But even a slight deterioration in the web saps its strength. Constant wrinkling of a thin web, (for instance, as the wing passes through bumpy air) sets

up fatigue stresses in the thin metal of the web—and this can have VERY SERIOUS consequences.

Sometimes a DIAGONAL member is used with the thin web to carry the heavy flying loads in TENSION during normal flight when the load is applied upward. With an INVERTED FLIGHT LOAD—that is, a load applied downward—the thin web is assigned to carry heavy tension loads while the diagonal assists by carrying the COMPRESSION load, and is braced against buckling by the tension in the thin sheet.

In a thin-web wing beam the web has to be well-designed. Otherwise tension stresses tend to pull the flanges together as in figure 16.

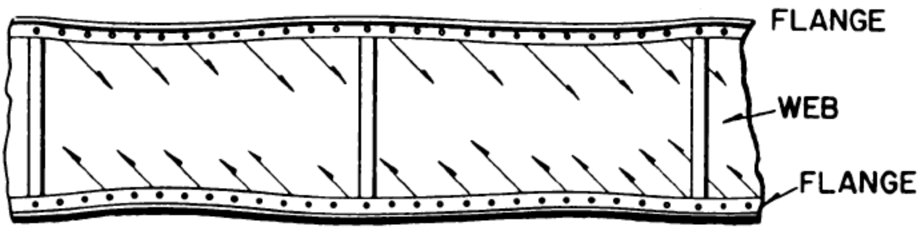


Figure 16.—The flanges bend due to tension in the web.

These stresses, of course, affect the rivets in the beam also. The RIVETS WHICH CARRY THE GREATEST AMOUNT OF SHEAR STRESS are those at the JOINTS where vertical members and flanges meet. Stresses on the rivets BETWEEN vertical members are relieved by the binding on the flanges. The length of the arrows in figure 16 which show the amount and direction of web stresses borne by the rivets, make plain which rivets must bear the greatest loads.

Some thin web wing beams are designed so that the web is ASSUMED NOT TO WRINKLE. A nonwrinkling web, of course, requires thicker material. It is easier to repair, however, because the stresses are less.

BOX WING BEAMS

A box wing beam has TWO WEBS, as in (*A*) and

(*B*) of figure 17. Here the entire wing, excluding the leading and trailing edges, is the box beam. In such a wing, THE FLANGES OF THE BEAM ARE THE TOP AND BOTTOM SURFACES OF THE WING.

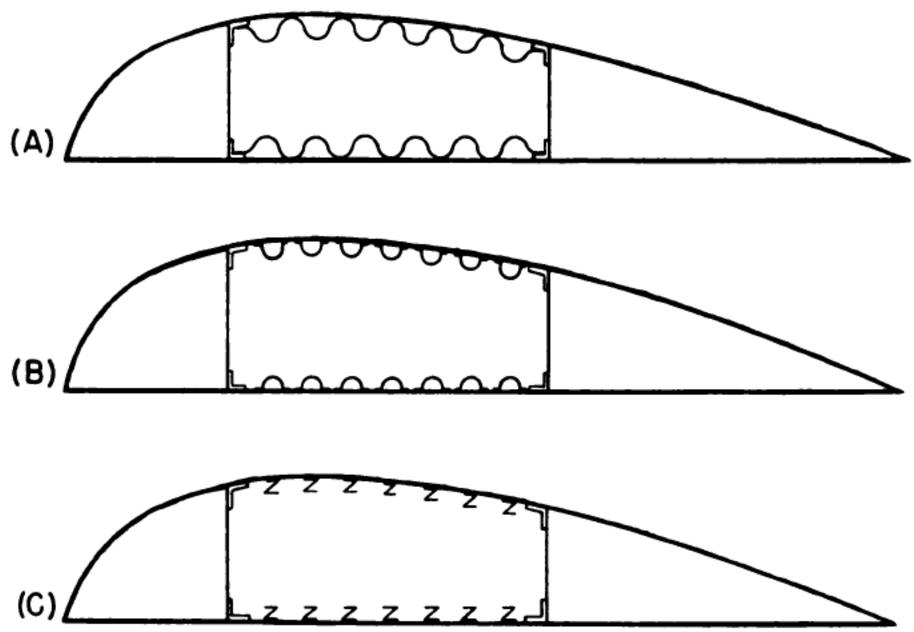


Figure 17.—Cross sections of some types of box wing beams.

In figure 17, these webs take the POSITION, but NOT THE PLACE, of wing SPARS. The webs do not take over the same functions as would spars in that position.

The FLANGES—that is, the top and bottom surfaces—of this kind of wing (sometimes called a stressed-skin wing) have to carry a heavy compressive load. Therefore, the designers have provided against BUCKLING OR WRINKLING in two ways.

First, the RIBS, which in this kind of wing serve as bulkheads, brace the flanges against buckling to some extent. Then, the metal is sometimes CORRUGATED to prevent wrinkling. Or if left smooth, stringers are put in running lengthwise of the wing to carry the compressive load.

A box wing has great TORSIONAL stiffness. In this respect it is like a large diameter tube. This torsional STIFFNESS is a quality of a box wing beam APART from

its strength, just as a paper tube is quite stiff, even though it has little strength. Such torsional stiffness gets around the tendency of the wing to FLUTTER at the terrific speeds which airplanes achieve.

MULTISPAR WING

You have just found out that the two webs of a box wing beam ARE NOT SPARS, even though they take the position of spars in the wing. In a true multispar wing, the spars take the position of these webs in the box beams. BUT they do not bear the shear loads which the webs of a box beam carry. Instead, they carry tension and compression, thus acting like the FLANGES of a box beam.

It is the SKIN of a multispar wing which acts like a web in a box beam wing. The skin carries shear stress for the chord load—that is, the load from leading to trailing edge of the wing. RIBS help transmit this load from the skin to the spars. The skin also gives the multispar wing great torsional stiffness.

MONOSPAR WING

A MONOSPAR wing has, as its name implies, only one spar. But it can be made just as strong as a multispar wing.

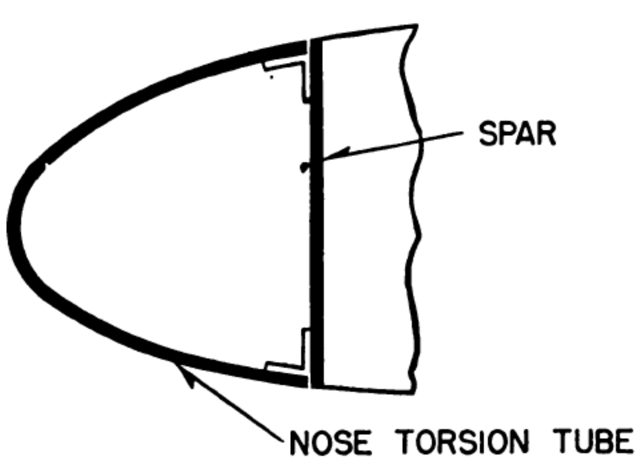


Figure 18.—Cross section of nose of a monospar wing.

One of the ways it is given strength is by making the nose section and spar ONE CONTINUOUS PIECE—like a large tube, as in figure 18.

As you already know, a thin-walled tube has great torsional rigidity. And the necessary strength—as distinguished from rigidity—can also be designed into such a tubular structure.

The trailing edge of a monospar wing gets its strength from the ribs which distribute the trailing edge load to the spar. The covering of the trailing edge can even be made of fabric for lightness, since THE SKIN HERE DOES NOT HELP TO SUPPORT THE WING.

WING CONNECTIONS

Wing connections are important to you because they are used to distribute all kinds of stresses. Consider for a moment a connection in a wing beam between the wing-tip section and the center section.

Such a connection passes along the TENSILE and COMPRESSIVE stresses of the FLANGES in the beam and also the SHEAR stresses in the WEB.

For example, in a wing built on trussed spars, the connection consists simply of fittings at the ends of chord members which pass along the load in the chord members. In such a wing, the truss of the center section and that of the tip section both have VERTICAL WEB MEMBERS at the joint. Thus, you have TWO VERTICAL WEB MEMBERS FUNCTIONING SIDE BY SIDE to make the joint strong.

In a box-type stressed-skin wing, special care is taken to see that the connection at joints is made so that the skin DOES NOT WRINKLE AT the connection.

A very SMALL unevenness in the fitting can throw a HEAVY CONCENTRATED STRESS in the thin sheet of the skin which must support part of the load. The skin is usually reinforced for a few inches around the fitting to prevent LOCAL WRINKLING, and a bulkhead ring or some other stiffener at the joint distributes the stress smoothly into the skin.

If the flanges of such a box-wing have stringers to carry the compressive load, the stringers may end in a RIGID BULKHEAD RING at the joint of the center and wing-tip sections. This ring evens the loading of the stringers and provides for the joint connection. Some wings don't have this ring but make the connection by an individual fitting on each stringer which, of course, has the effect of making the stringer continuous.

A HEAVY REINFORCEMENT at each of the free ends of the webs of a box-wing beam is used to transmit the web shear stress. Such reinforcement passes along the stress through the FLANGE connection at the joint between center and wing-tip section. Or, these free ends of the webs can be connected by a PLATE which passes along the shear stress as if it were a part of the web.

FUSELAGES ALSO ACT LIKE BEAMS

The wing isn't the only part of an airplane that acts like a beam under bending stress. So DOES THE SEMI-MONOCOQUE FUSELAGE.

A semi-monocoque fuselage is a tube, you remember, but when such a tube is bent it has all the characteristics of a beam. A bending load VERTICALLY (tail loads, landing loads, etc.) sets up tension and compression stresses in the upper and lower stringers. Take another look at (*B*) of figure 12. The portions of the tube marked "Flange" correspond to the flanges of a beam, and they also correspond to the upper and lower stringers of a fuselage.

The sides of the tube—marked "Web"—perform the job of the web of a beam and carry shear stress under vertical loading.

For example, if you were pulling out of a power dive at a speed of 600 miles per hour, a terrific vertical force (tail load) would be applied through the elevators, and distributed to the aft end of the fuselage as the tail is forced down and out of the airplane's line of

flight. This force would cause a tension on the top of the fuselage, compression on the bottom, and shear on either side as shown in figure 19.

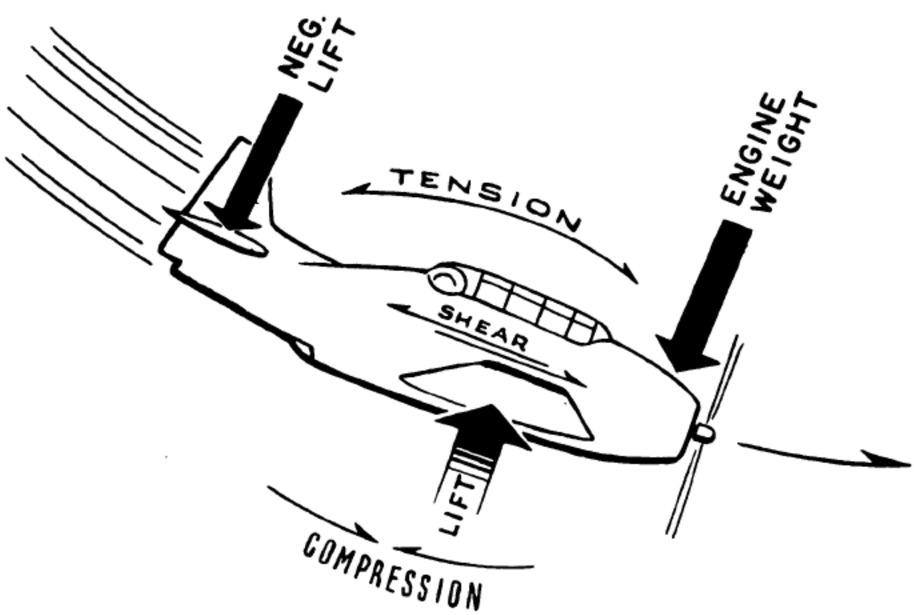


Figure 19.—Vertical loads.

On the other hand, suppose loading conditions on a fuselage are in a HORIZONTAL plane (rudder loads). When a fuselage is bent sideways, as in turning, the SIDES of the fuselage become the flanges of the beam and carry compression and tension. The top and bottom of the fuselage act like the web of a beam and carry shear loads.

Suppose you were hot on the tail of an enemy airplane at a speed of 400 miles per hour and suddenly made a sharp horizontal turn to the right. What happens? The rudder load forces the tail to the side and builds up a tension on the right side of the fuselage, compression on the left side, and shear on the top and bottom. Figures 19 and 20 compare the effects of vertical and horizontal loads. Normally vertical loads are greater than loads in the horizontal plane.

In the case of rudder loads you can see that the door of the fuselage would cut ENTIRELY ACROSS the FLANGE portion of the beam. But the reinforcing structure

around the door is designed to carry this flange load—which may be either TENSION or COMPRESSION. The reinforcement around the door makes it possible for these stresses to TAKE A DETOUR around the top and bottom of the door thus avoiding stresses directly upon the weak spot of the door-opening. Window reinforcement has the same purpose. Stress is transmitted around the window by the window frames.

Like the wings, the fuselage is also subject to TORSIONAL STRESSES.

When an airplane propeller is turning through the air at high speeds in one direction, the fuselage has a tendency to turn in the opposite direction. To keep the aircraft flying on an even keel, the trim tabs on the wings and elevators are adjusted to oppose this action. Thus you have a TORSIONAL LOAD ON THE FUSELAGE. In practically all twin-engine airplanes, the same result is produced by having one propeller rotate clockwise while the other rotates counterclockwise. Notice in figure 21 that this torsional loading subjects the fuselage to torsion and compression at a 45° angle.

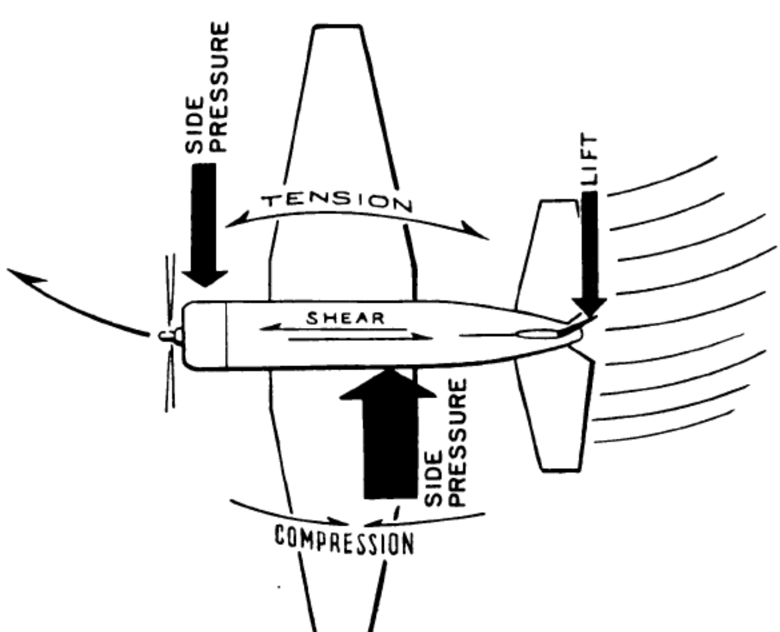


Figure 20.—Horizontal loads.

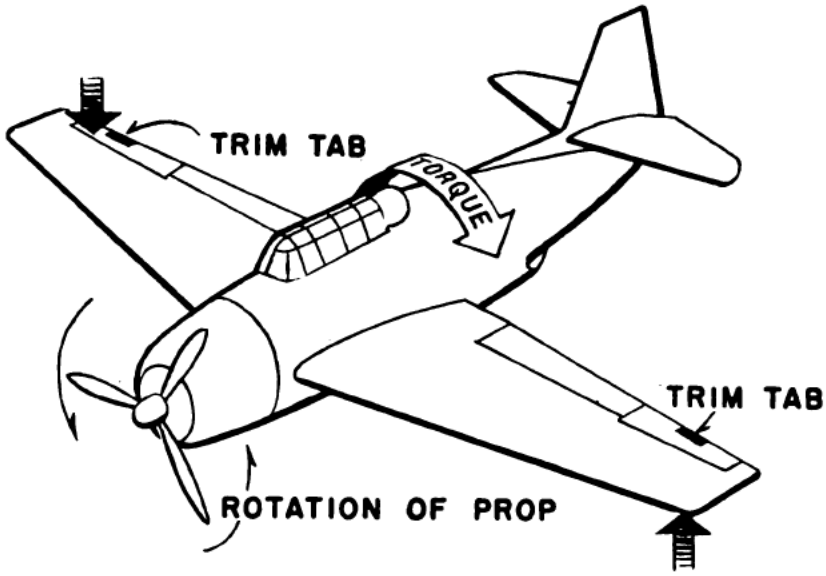


Figure 21.—Torsional load.

SOME MORE MONOCOQUE STRUCTURES

Recent designs of fixed tail surfaces or FINS tend toward all metal semi-monocoque structures. Three kinds of fins are shown in figure 22. Notice the stiffening devices used to help the fin support bending and torsional loads.

Struts too, are usually designed on the monocoque principle. They consist of thin-walled tubes—either round or streamlined—and act as braces between the wings of bi-planes or for landing gears.

A strut which is in compression can be classified as either a LONG or a SHORT strut. A long strut is one so long in relation to its diameter than it BUCKLES.

A short strut is one so short in relation to its diameter that it will NOT buckle until after local wrinkling occurs. It is, of course, stronger than a long strut. Here are some things to remember about struts.

The strength of a strut is DOUBLED if the ends are fixed RIGIDLY. "Fixed" ends DO NOT mean ends welded or riveted to a gusset plate, because in such cases the whole structure at the joint may allow the strut to move or bend. Fixing the ends is equal to cutting

the length in half. Therefore the strut would be TWICE as strong.

If a strut is braced to a rigid frame in the middle, so that it is fixed at the ends AND at the middle, then its strength is FOUR TIMES GREATER, because its effective length is cut in half AGAIN. The strength of a strut is inversely proportional to the square of its length.

The strength of a strut does not depend upon the

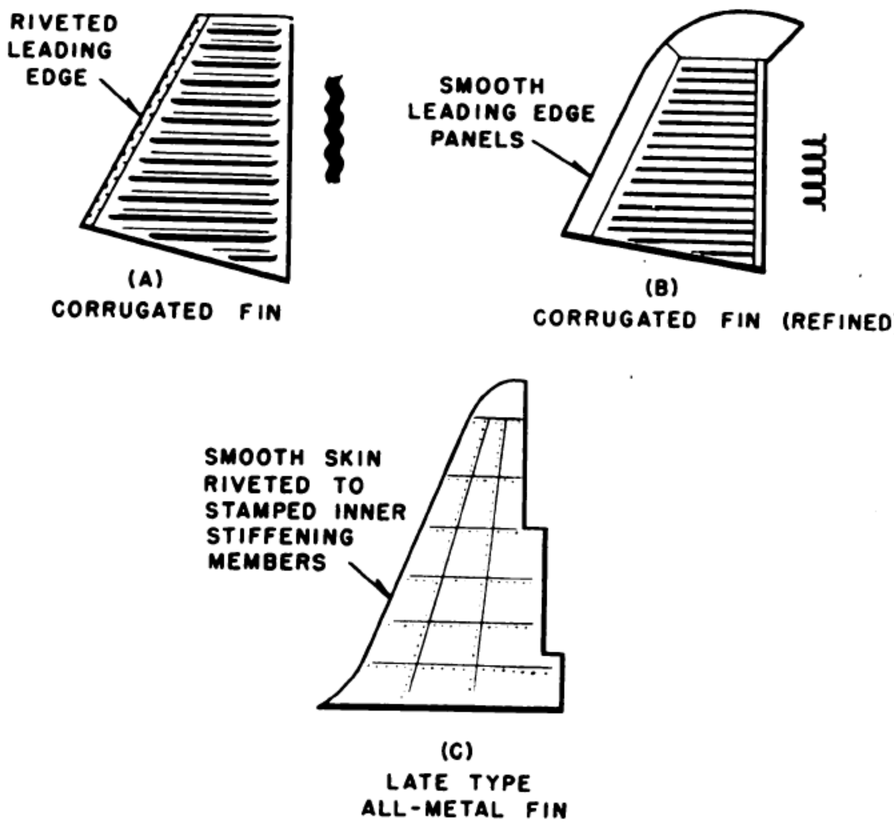


Figure 22.—Three monocoque fins.

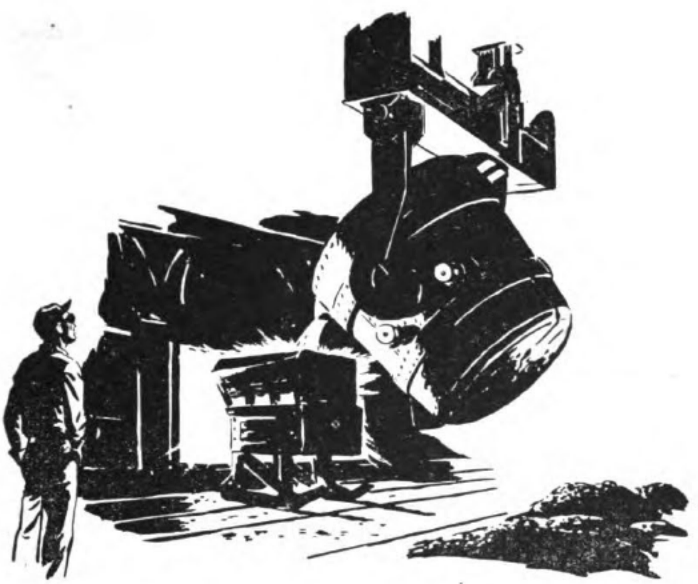
strength of the material. It depends upon and is proportional to its STIFFNESS—that is, the modulus of elasticity of the material. For instance, a strut of steel is three times as stiff as a duralumin strut.

The more it is possible to increase the diameter of a strut, the stronger it is.

There should be NO FREE EDGES in the cross section of a strut. A split in a strut exposes free edges which will wrinkle easily.

The ELASTIC LIMIT of the material in a strut decides the upper limit of the LOAD A STRUT CAN BEAR. For instance a duralumin strut with an ultimate strength of 60,000 psi but with an elastic limit of 40,000 psi could carry a load NO GREATER than 40,000 multiplied by the cross sectional area of the strut in square inches.

FAIRINGS, such as fillets, propeller spinners, landing gear "pants," etc., while normally not designed to carry any major structural loads, are often of semi-monocoque construction. The advantage of this type of construction here is that the weight of the part is minimized without sacrificing the rigidity necessary to maintain the true shape of the structure.



CHAPTER 2

FERROUS METALS

ABC'S OF IRON

An object that is FERROUS is one that pertains to iron or is derived from iron. So much for the definition.

While pure iron itself is not considered an aircraft metal, members of its family are. This fact, coupled with the fact that you may be called upon to work with equipment which uses iron in some form, makes a knowledge of ferrous metals important.

For centuries iron was as valuable as gold. It was used as coins and was sold in market places along with silks and furs. And many centuries passed before it was produced on a commercial basis.

Excepting only aluminum, iron forms a larger part of the earth's crust than any other metal. It occurs in large deposits as oxides, sulfides and carbonates and less abundantly in a great variety of minerals. Iron is so ductile it can be drawn out thin like taffy and so malleable it can be shaped by beating with a hammer or by putting it through rollers. The toughest

of all the ductile metals, a sheet of iron can be hammered so thin that it weighs less than a sheet of ordinary writing paper of the same size. This metal is strongly attracted by magnets, rusts readily in moist air, but is resistant to other forms of corrosion.

Unlike many of the other common metals, iron is rarely found in a pure state, and in that state is of limited practical use. When found with other substances, however, it shows many qualities that increase its value.

CARBON is practically always found in iron ore—MANGANESE, SILICON, and traces of PHOSPHOROUS, SULPHUR and OXYGEN are also usually found in it. This variation in formation plus the types of treatment of the ore during manufacture produce many kinds of finished products. The three principal ones are CAST IRON, WROUGHT IRON, and STEEL.

THERE ARE MANY KINDS OF CAST IRON. All of them are produced by remelting pig iron. Three types of furnaces—cupola, air, and electric—are used for this work. The furnace used depends upon the type of cast iron that is to be manufactured. Cast iron is used where parts of machines cannot be shaped economically from steel, or where the greater strength of steel is not needed. Cast iron is very brittle and, therefore, will not withstand shock.

However, cast iron does have certain qualities that make it ideal for castings. It shrinks very little during solidification. It has a lower melting point than steel. And it is much cheaper than steel.

By way of classification, cast iron may be divided into four groups—GRAY, WHITE, MALLEABLE, and ALLOY.

GRAY CAST IRON

GRAY CAST IRON—the ordinary commercial iron—is generally made in a cupola, which is a cylindrical steel furnace lined with fire brick.

The quality and kind of cast iron produced depend largely on how carbon is found in the metal—whether separately as graphite or combined with the iron. The amount of silicon contained in the metal is the second determining factor, as silicon promotes the change from combined carbon to graphite. Thus, when you have a high silicon content and allow the molten metal to cool slowly, a large part of the carbon is found in the form of flakes of graphite. (Graphite is black and gives the iron both a dull appearance and its name.) The slower the cooling, the larger the flakes of graphite. A large casting has large flakes because it cools more slowly than a small one. The chips of graphite cut across the iron in all directions, and act like cracks in breaking up the structure of the iron and making it weak and brittle. Graphite is an excellent lubricant, and for that reason GRAY CAST IRON IS EASILY MACHINED. Gray iron has a high compression value, a low tensile strength, and no ductility.

WHITE CAST IRON

WHITE CAST IRON is produced when cast iron is cooled rapidly, leaving the carbon mostly in the combined form.

This metal is strong and brittle, and so hard that it is exceedingly difficult to machine. Because of this difficulty, white cast iron is not generally used for ordinary castings. It is used instead for parts that get considerable wear but no direct stress, and for malleable castings. Special cutting tools or grinders must be used to machine this type of iron. It is called "white cast iron" because a fractured surface is fine-grained, is white, and has a bright metallic luster.

MALLEABLE CAST IRON

MALLEABLE CAST IRON is white cast iron that has been put through an annealing process which changes

the iron from a hard, brittle material to a soft, tough one. This annealing process produces a casting that has considerable shock resistance and good machinability.

MALLEABLE CASTINGS RANGE IN STRENGTH BETWEEN THAT OF GRAY IRON AND STEEL CASTINGS, and so are used where gray iron is too weak and steel is too expensive. They will bend, twist, and resist shock even better than cast steel.

ALLOY CAST IRON

Remember that flaky graphite carbon in gray cast iron makes it coarse and porous, and therefore weak. There are ways of remedying this defect. If you ADD NICKEL TO THE MOLTEN METAL, the graphite flakes tend to become smaller. This strengthens the iron without lessening its machinability. Then, too, nickel has both great hardness and great malleability—two qualities needed by the iron.

CHROMIUM IS ANOTHER GOOD ALLOY FOR THIS PURPOSE. When added to cast iron, chromium has the double value of increasing the hardness and improving resistance to both corrosion and heat. Molybdenum, when used as an alloy, increases both strength and durability.

STEEL

STEEL IS A MASTER METAL. It is the backbone of our industrial civilization, and its importance in winning the war cannot be overemphasized. Did you know that around five tons of steel are required to make a big bomber? Did you know that tens of thousands of tons of steel are needed to build a large aircraft carrier? Fortunately, the United States can produce more steel than all the rest of the world combined.

Steel is used widely in aircraft construction, wherever great strength is necessary. Navy airplanes used for

training purposes have fuselages built of steel tubing welded together at the joints. In all types of airplanes, you find almost invariably that landing-gear axles and engine mounts are made of steel. You also find steel used for fittings.

Two types of steel are employed in aircraft work—CARBON STEEL and ALLOY STEEL. Both types are used, BUT alloy steel is used in practically all airplanes.

Alloy steels show greater strength than do the carbons. They bear up better under compression and shearing strains, too.

Alloy steels are tough, durable, and do not corrode

Figure 23.—Aviation Metalsmiths work at advanced bases.

easily. Some of them have a special quality of FATIGUE RESISTANCE that makes them particularly suited to aircraft work. Fatigue resistance IS MUCH THE SAME IN METAL AS IN PEOPLE—the ability to stand repeated strain or shock without cracking up.

Alloy steels were brought into the picture primarily because of their STRENGTH-WEIGHT RATIO, which is definitely higher than that of the mild, or low-carbon, steels. Thus, if you have a piece of carbon steel and a

piece of alloy steel, both of the same weight, the alloy steel is much stronger. With proper care during heat treatment, they'll develop from four to five times as much tensile strength as the carbon steels.

High strength-weight ratio is an important factor in aircraft construction where weight must be kept down and strength up. Probably the most popular alloy steel for aircraft use is CHROME-MOLYBDENUM, commonly known as CHROME-MOLY, which is made by mixing chromium and molybdenum with the steel. The widespread use of chrome-moly in aircraft construction is due to its excellent welding qualities, its ease of

Figure 24.—Aviation Metalsmiths repair a wing tip.

forging, its response to heat treatment, and its availability in practically every form.

There are many other kinds of alloy steel, however. NICKEL STEEL is well known, and VANADIUM STEEL and MANGANESE STEEL are used a great deal.

The qualities of both carbon and alloy steels are influenced by three factors—the HEAT TREATMENT given them, their CHEMICAL COMPOSITION, and the MECHANICAL WORK done on them.

IDENTIFYING STEELS

Before plunging deeper into the subject of steel, you should know the method by which steels are identified.

Memorize the Society of Automotive Engineers (SAE) index of numbers and know HOW IT WORKS. You will be using it ALL THE TIME you work as an Aviation Metalsmith.

The SAE numbering system is commonly used to designate the steels which are used in aircraft and automotive construction. It is a simple system. The major alloying element is identified by a number and the carbon content is indicated by two or three digits.

Because a numerical index is used to identify the compositions of SAE steels, it is possible to use numbers on shop drawings and blueprints. These numerals partially describe the composition of the material covered by them. The first digit indicates the TYPE of steel. The numeral "1-," for instance, indicates a carbon steel; "2-" a nickel steel, and "3-" a nickel-chromium steel.

TABLE I

STEEL COMPOSITION

SAE 2340

2 3 40

(2) Nickel Steel

(3) Approx. 3% nickel

(40) Approx. 0.40% carbon

For the SIMPLE ALLOY steels, read the second digit for the approximate percentage of the PREDOMINANT alloying element. Usually, the last two or three digits indicate the average carbon content in "points" or hundredths of one percent. In this way you can see that 2340 indicates a nickel steel of approximately

three percent nickel (3.25 to 3.75) and 0.40 percent carbon (0.35 to 0.45). The number 71360 indicates a tungsten steel of about 13 percent tungsten (12 to 15) and 0.60 percent carbon (0.50 to 0.70). See tables I, II, and III.

TABLE II

STEEL COMPOSITION

SAE	71360

7 13 60

(7) Tungsten Steel

(13) Approx. 13% tungsten

(60) Approx. 60% carbon

CARBON STEELS

Carbon steels contain CARBON, MANGANESE, SILICON, SULPHUR, AND PHOSPHORUS. The first three of these are available to the steel because desirable properties are added, or because they clean and purify the molten metal. Sulphur and phosphorus, however, are harmful, so you'll find the quantity of each of these kept as low as possible.

You find three principal types of carbon steels—low, medium, and high. The amount of carbon varies with the USES for the finished steel.

LOW CARBON STEELS contain from .10 to .30 percent carbon. The one you'll probably be using most in aircraft work is SAE 1025. Since its carbon content is low, it's not very hard and you'll find it easy to machine, weld, bend, and forge. However, its use in aircraft is pretty limited because it has low strength.

TABLE III

SAE STEEL NUMBERING SYSTEM

Type of Steel	Numerals (and Digits)
Carbon Steels	1xxx
Plain carbon	10xx
Free cutting (screw stock)	11xx
Free cutting, manganese	X13xx
High Manganese	T13xx
Nickel Steels	2xxx
0.50% nickel	20xx
1.50% nickel	21xx
3.50% nickel	23xx
5.00% nickel	25xx
Nickel Chromium Steels	3xxx
1.25% nickel, 0.60% chromium	31xx
1.75% nickel, 1.00% chromium	32xx
3.50% nickel, 1.50% chromium	33xx
3.00% nickel, 0.80% chromium	34xx
Corrosion and heat-resisting steels	30xx
Molybdenum Steels	4xxx
Chromium	41xx
Chromium nickel	43xx
Nickel	46xx & 48xx
Chromium Steels	5xxx
Low chromium	51xx
Medium chromium	52xxx
Corrosion and heat-resisting	51xxx
Chromium Vanadium Steels	6xxx
Tungsten Steels	7xxx & 7xxxx
Silicon Manganese Steels	9xxx

Medium carbon steels are those with a carbon content ranging as high as .50 percent carbon. This increases their strength considerably but they can't be fabricated or welded as easily as the low carbons.

High carbon steels contain carbon ranging from .50 to 1.05 percent. When other alloying materials are added, a very hard steel which will withstand considerable wear is formed. Use of high carbon steel is somewhat limited in aircraft construction. SAE 1095 is used for making springs but for other than that it is used very little in aviation.

The prefix "X" (see table III) is used in several instances to denote variations in the range of manganese, sulphur, or chromium. The prefix "T" is used with the manganese steels (1300 series) to avoid confusion with steels of somewhat different manganese range that have been identified by the same numerals but without the prefix.

ALLOY STEELS—CREAM OF THE CROP

Among those tough, durable materials that make your Navy's aircraft better than anything the enemy has to offer are the alloy steels. Some of them are nickel steels produced by combining nickel with carbon steel. These have a nickel content ranging from .50 to 5.00 percent. Nickel increases the hardness, tensile strength and elastic limit of the steel. You can readily see this in SAE 2330 which is used for such parts as bolts, terminals, clevises, and pins. It makes aircraft bolts so tough that you can bend them almost double before they will break. You'll see plenty of nickel steel in the aircraft industry.

When nickel and chromium are mixed in various proportions with steel, you have chrome-nickel steel. That's another one that is highly important to Naval Aviation. About one to two times as much nickel as chromium is used in the alloying. Both elements influence the steel. Nickel gives it toughness. Chromium

hardens it. Chrome-nickel steel is used for machined parts and drop-forged parts requiring great strength. Parts like your crankshafts, link rods, knuckle pins, and so on, are made of SAE 3140.

MOLYBDENUM STEELS are widely used in aircraft construction because molybdenum adds valuable qualities to the natural qualities of steel. Molybdenum adds to the ultimate strength without affecting the ductility or workability of the metal. You'll find molybdenum steels tough, wear-resistant, and readily hardened by heat treatment. They are especially adapted for welding and for this reason are used principally in welded tube structures such as fuselages and engine mounts.

CHROMIUM STEELS are high in strength, hardness, and corrosion-resistant properties. Chromium steels such as SAE 51235 are especially adaptable for heat-treated forgings which require greater toughness and strength than you can get in other alloys. You'll find this steel in such things as ball and roller bearings.

VANADIUM is another alloy which has very much the same effect as nickel when added to steel. As little as one-fourth of one percent of vanadium will increase the strength, and the yield point will be increased as much as 50 percent. YIELD POINT, by the way, is a point beyond the elastic limit of the metal. Vanadium is very essential where there is need for resistance to impact, vibration, and reversals of stress such as those found in transmissions and axles. It also increases the cutting power of high speed alloy cutting tools.

TUNGSTEN STEEL is not used to any great extent in aircraft today except in the engines. There you'll find it used as a material for exhaust valves because of its extreme hardness at high temperatures.

SILICON in steel acts as a cleaning and purifying agent. It eliminates harmful gases, producing a steel which is free from blowholes. Combine silicon and manganese and you have a steel with a great resistance to shock. Steel with this combination is used in springs and gears which are subjected to severe impacts.

High up on the list of "must" materials for Naval Aviation are corrosion-resistant steels. They're vital because a majority of Naval aircraft operate under salt water conditions.

One of the more common types is STAINLESS STEEL, usually referred to as "18-8." This is a chrome-nickel steel containing approximately 18 percent chromium and eight percent nickel. It is highly resistant to any kind of corrosion. You'll find it used extensively in plate and sheet forms, on exhaust stacks, collector rings, and manifolds. It is used throughout the Fleet for safety wire.

Not a ferrous metal, but important in the fight against corrosion is MONEL METAL—the leading high-nickel alloy of the nickel-copper series. It's a "natural," being made from a mixed nickel-copper ore. It contains from 65 to 68 percent nickel and about 29 percent copper. The remainder consists of iron, manganese, and cobalt. Monel is harder and stronger than either nickel or copper in the pure form, and has good ductility. It is cheaper than pure nickel, and can often be used to better advantage. It has a very high corrosion resistance, and is substituted for steel where such resistance is a primary consideration. It shows good strength at high temperatures. And last, but not least, Monel makes a nice appearance, being silvery white in color.

In aircraft, Monel has long been used for parts which need both strength and high resistance to corrosion, such as exhaust manifolds and carburetor needle valves and sleeves. Nuts, bolts, control parts, and fittings are manufactured from it and, recently, experimental seaplane floats have been built of it.

"K" MONEL possesses the excellent corrosion resistance of the parent metal, together with the added advantages of greater strength and hardness. In it you have a non-ferrous alloy with the higher strength ordinarily found only in heat-treated alloy steels.

The fact that "K" Monel retains its non-magnetic and corrosion-resisting qualities at subnormal temperatures makes it valuable in aviation instruments, such as the plotters on the wide-cruising patrol bombers. It is used also in roller chain for retractable landing gear and for the control of airplanes.

INCONEL is a high-nickel alloy carrying 78½ percent nickel, 14 percent chromium, 6½ percent iron, and minute amounts of manganese, copper, silicon, carbon, sulfur, and cobalt. It has great corrosion resistance, retains strength at high temperatures, and remains

Figure 25.—Welding stainless steel exhaust stack.

bright under exposure to sulfur compounds and a great variety of corrosives.

In addition to this corrosion resistance, Inconel possesses a very desirable combination of high strength and workability for both hot and cold working. Its tensile strength is much higher than that of stainless steel. And its compressive, shear, and torsional strengths are adequate.

Its ability to resist the effects of combustion gases and to retain strength and ductility at elevated tem-

peratures make Inconel valuable for airplane exhaust stacks and manifolds, collector rings, cowling around the exhaust pipes, firewalls, shrouding, exhaust gas analyzer tubes, and cabin heater boilers. Its nonmagnetic quality adapts it for use around compasses.

CHAPTER 3

NON-FERROUS METALS

ALUMINUM IS HANDY STUFF

Naval Aviation depends heavily on the material that kitchen pots and pans are made of. In one form or another, that stuff—ALUMINUM—has contributed mightily to the Air Age.

Aluminum is a white, lustrous metal. It is light in weight. It has good corrosion-resistant properties, and a high thermal conductivity. It is very ductile and malleable, and is non-magnetic.

COMMERCIAL aluminum ordinarily contains not more than one percent of other elements. The other elements, principally iron and silicon, are regarded as impurities—so the metal is usually referred to as PURE ALUMINUM.

But while pure aluminum is very light in weight and has good corrosion-resistant properties, it is lacking in tensile strength. That limits its use in aircraft construction. Its ductility makes it suitable for parts which require severe forming operations; and a major use of

TABLE IV

NOMINAL COMPOSITION OF WROUGHT ALUMINUM ALLOYS

[Percent of alloying elements. Aluminum and normal impurities constitute remainder]

Alloy	Copper	Silicon	Manganese	Magnesium	Zinc	Nickel	Chromium	Lead	Bismuth
2S	....	....	....	....	....	....	....	....	....
3S	....	....	1.2	....	....	....	....	....	....
4S	....	....	1.2	1.0	....	....	....	....	....
11S	5.5	....	....	....	....	....	....	0.5	0.5
14S	4.4	.8	.8	.4	....	....	....	....	....
17S	4.0	....	.5	.5	....	....	....	....	....
A17S	2.5	....	....	.3	....	....	....	....	....
18S	4.0	....	....	.5	....	2.0	....	....	....
24S	4.4	....	.5	1.5	....	....	....	....	....
25S	4.5	.8	.8	....	....	....	....	....	....
32S	.8	12.0	....	1.0	....	.8	....	....	....
51S	....	1.0	....	.6	....	....	....	....	....
A51S	....	1.0	....	.6	....	....	.25	....	....
52S	....	....	....	2.5	....	....	.25	....	....
53S	....	.7	....	1.3	....	....	.25	....	....
56S	....	....	.1	5.2	....	....	.1	....	....
70S	1.0	....	.7	.4	10.0	....	....	....	....

the pure metal is as pigment in dope or paint to give a metallic covering to other metals and fabric-covered surfaces. You'll also see it in non-structural airplane parts such as fairings and fillets.

Aluminum ALLOYS, however, are used in structural parts. And how!

The two main classes of alloys with which you will be concerned are the WROUGHT alloys and the CASTING alloys. Of these two, the wrought alloys are the most widely used in aircraft construction. They are used for stringers, bulkheads, skin, rivets, and extruded sections. Wrought alloys may be used for almost any desired shape.

Casting alloys are not so extensively used in airplanes as the wrought alloys. But you will find them in fittings and in such parts as cylinder heads and pistons for aircraft engines.

WROUGHT ALLOYS HAVE A CODE

Alloys have become so numerous that it has become necessary to label them. Wrought alloys are designated by a number followed by the letter "S." The number indicates the TYPE of alloy. In the case of 24S, it would be an aluminum alloy containing 4.4 percent copper, .5 percent manganese, 1.5 percent magnesium. Table IV gives you some of the wrought alloys and the various elements which go to make them up.

Following the letter "S" you may find additional letters or numbers. These indicate TEMPER OR HARDNESS of the alloy, as well as the way in which the hardness was obtained.

The letter "T" is used to show that the metal has been heat treated and fully aged. This will follow the letter "S."

In addition to the letter "T" the letter "R" is sometimes added for some alloys. The "R," however, goes BEFORE the "T." In the case of a wrought alloy of 24S type which has been heat treated and aged, and then

has been strain-hardened by cold working to give it additional strength, the symbol "24S-RT" is used. Alloy 24S-RT is used a great deal for aircraft skin and in places where a minimum amount of fabrication is necessary.

You also find several of the wrought alloys with the letter "W" following the letter "S." The "W" indicates that the alloy is in the partially aged condition, and in order to be made fully hard it must be given artificial aging.

Both heat treatable and non-heat treatable alloys may be obtained in a soft or annealed condition. This is shown by the letter "O" following the "S," indicating the metal is in the dead soft or annealed condition.

You can obtain the non-heat-treatable alloys in different tempers. They are indicated by the numbers and letters below.

O .... Dead soft (annealed)
¼ .... One quarter hard
½ .... One-half hard
¾ .... Three-quarters hard
H .... Hard

The metal you use will be marked in the way just described. But remember that you can't do anywhere near your best work until you know what the markings ARE and what they MEAN.

There is one other marking you'll find occasionally—the letter "A" in front of the type alloy number. As an example, "A17ST" would indicate that some other element has been added to the 17S to give it some specially desired property. In the case of an A17S rivet, it may be driven as it is received, acquiring its strength from being driven.

Wrought alloys are broken down into two principal groups. Some are treated with heat and some cannot be treated in that way.

Of the non-heat-treatable alloys, the most common are 2S, 3S, and 52S. The most widely used is 52S. Non-

heat-treatable means just what the name implies. You can't harden or strengthen it BY ANY MEANS of heat treatment. The only way you can harden these metals is by cold working—by running them through rolls or forming.

If the metal becomes too hard from cold working, you can soften it by annealing. When 52S tubing is used in an airplane, you must take it off at regular intervals and anneal it. Otherwise it will become work-hardened and eventually will crack. You'll find that practically all cowling and fairing on Naval aircraft is made of 52S aluminum alloy.

In the heat-treatable groups there is a much greater variety of alloys, but the two main types with which you will work are 17S and 24S. These are much stronger than the non-heat treatable alloys and are obtained in almost any desired form—sheet, tubing, rivets, extruded sections, etc.

The oldest of the heat-treatable alloys is 17S. It has largely been replaced by 24ST and 24S-RT alloys. About the only form in which you can get 24S-RT is sheet stock. Because of this, its use is largely limited to skin covering. Most aluminum alloy structural members are made of 24ST.

Two new high-strength alloys have been developed and are starting to take the place of 24S in aircraft construction. They're designated as "75S" and "R301." Each is made by a different company, but their physical properties are much the same. They compare favorably in tensile strength to some of the structural steels. Since these metals are comparatively new, there's little specific information about them available now. However, the Bureau of Aeronautics will release details when these metals are brought into general use on Naval aircraft.

Table V will show you the uses of various forms of aluminum alloys.

Aluminum casting alloys, like the wrought alloys, are divided into two groups. In one, the physical

TABLE V

NAVY DESIGNATION OF AND USES OF ALUMINUM ALLOY

NONSTRUCTURAL

Material and forms	Navy specification No.	Alloy No.	Purpose
Aluminum sheet	47-A-2	2S	Welded tanks, junction boxes, and miscellaneous small parts.
Aluminum tubing	44-T-19	2S	
Aluminum rods, wire	46-A-3	2S	
Aluminum rivets	43-R-5	2S	
Aluminum coil	47-A-5	2S	
Aluminum welding wire	46-R-1	2S	
Aluminum alloy manganese:			
Sheet	47-A-4	3S	Welded tanks, junction boxes, and small parts.
Tubing	44-T-20	3S	
Bars, rod, etc.	46-A-6	3S	
Rivets	43-R-5	3S	
Aluminum alloy manganese-magnesium:			Welded tanks, fuel and oil lines.
Sheet	47-A-9	4S	Difficult shapes, welded, such as nose cowling, fairing, etc.
Tubing	44-T-24	4S	
Rods, bars, etc.	46-A-8	4S	
Welding rod	[1]46-R-1	4S	
Aluminum alloy Cu-MGOMN-Cr:			
Sheet	47-A-11	52S	Cowling, fuselage, fairing, and streamlining, fuel and oil lines, etc.
Tubing	44-T-32	52S	
NOTE.—This alloy is preferable to the above (2S, 3S and 4S) and should be used for the above purposes.			

STRUCTURAL (HEAT-TREATED)

Aluminum alloy Al-Cu-Mg-Mn:			All structural shapes, frames, struts, skin (floats and hulls), wings, fuselages.
Sheet	47-A-3	17ST	
Tubing (round)	44-T-21	17ST	
Tubing (streamline)	44-T-22	17ST	
Bars, rods, wire	46-A-4	17ST	Balancing surfaces, etc.
Forgings	46-A-7	17ST	
Rivets	43-R-T		
Aluminum alloy Al-Cu-Mg-Mn: Sheet	47-A-10	24ST	
NOTE.—This alloy is preferable to the above (17ST) and should be used for all structural purposes.			
Bar, rod, shapes	46-A-9	24ST	

[1] Grade E.

properties of the alloy are determined by the elements added and cannot be changed after the metal is cast. In the other, the elements added make it possible to heat treat the casting to produce desired physical properties.

You identify casting alloys by a letter PRECEDING the alloy number, while in wrought alloys the letter follows the number.

In the case of casting alloy 214 the addition of zinc to obtain certain desired properties is designated by the letter "A" in front of the number. This gives you the designation A214.

Where you have heat treated castings, you indicate the heat treatment and composition of the casting by the letter "T" followed by an alloying number. An example of this is the sand casting alloy 355. This has several different compositions and tempers and is designated as 355-T6, 355-T51, and A355-T51.

Aluminum casting alloys may be poured in SAND MOLDS, PERMANENT MOLDS, or may be DIE-CAST.

In casting aluminum you must remember that in most cases different type alloys must be used for the different types of castings. Sand castings require a different type than permanent molds. The same holds true in the case of die castings.

The two principal types of sand casting alloys are 112 and 212. From a mechanical properties consideration, there is little difference between the two. But you'll find that the 112 is slightly better for machining than the 212.

HEAT TREATED sand castings, however, are in more extensive use than the ones just mentioned. You'll find alloys 142, 355, A355, and 356 commonly used for aircraft engine cylinder heads and accessory housings.

In permanent mold castings there are two specific types. The permanent metal mold with metal cores and the semi-permanent type which has sand cores instead of metal. Because finer grain structure is produced in alloys subjected to the rapid cooling of

metal molds, they are far superior to the sand type casting.

Alloys 122, A132, and 142 are commonly used in permanent mold castings. Their principal use is for pistons in internal combustion engines. All permanent mold castings require a smaller amount of machining. That makes them much better than the sand type casting.

COPPER IS IMPORTANT

Like aluminum, COPPER in its pure form has important but limited use in aircraft construction.

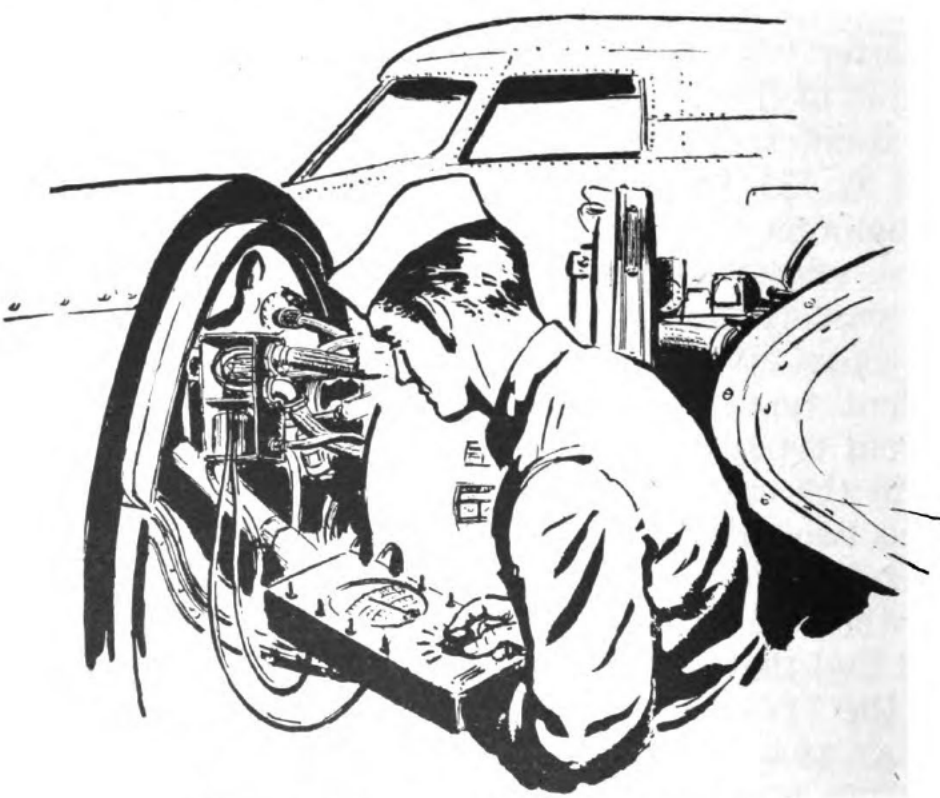


Figure 26.—Copper is essential for wiring.

Copper's use as a structural material is limited because of its great weight—approximately 555 pounds to the cubic foot. But some of its outstanding characteristics, such as its high electrical and heat conductivity, in many cases over-balance the weight problem.

So you will find copper used THROUGHOUT the airplane, particularly in the power plant.

The more important uses of copper in aircraft construction may be summarized in this way:

In short form or strips for —

- Gas and oil tanks.
- Flashing (weather protection) on floats and wooden hulls.
- Bending where ribbon is used.
- Shims (filler strips) and washers.
- Tips for wooden propellers.

In tube form for—

- Gas and oil lines.
- Leads of airspeed meters.
- Water lines.
- Radiator cores.
- Heater coils.

In wire form for—

- Ignition wiring.
- Radio wiring.
- Lighting wires.
- Safety wiring.
- Tacks for wooden floats and hulls.
- Bonding.

The copper used in the manufacture of COPPER TUBING must be at least 99.90 percent pure. Standard requirements for aircraft fuel, oil, and water lines call for sizes ranging from 1/8 to 1 1/8 inches outside diameter. A wall thickness of 35/1000-inch is used for pipe with diameters less than 5/8-inch, and a thickness of 49/1000-inch is used for the larger diameters.

However, copper-silicon-bronze tubing has largely replaced copper tubing for fuel, oil, water, and air lines. It is considerably stronger than pure copper tubing and can be annealed at 1,000°-1,100° F.

Among the copper-aluminum alloys, the ALUMINUM BRONZES rank very high in the aircraft field. You'll find wrought aluminum bronzes just about as strong and ductile as medium carbon steel. In addition, they

possess a high degree of resistance to corrosion by air, salt water, and chemicals. You can forge them readily, and many of them take heat treatment.

Aluminum bronzes have great strength, hardness, and resistance to both shock and fatigue. Because of these properties, their uses in aircraft engine construction alone are many. You find them in such items as valve seats, valve guides, propeller hub cones, spark plug inserts, bushings, and nuts. One of the leading aircraft engine manufacturers uses at least 85 parts made from one of the aluminum bronze alloys.

PHOSPHOR BRONZE is a general term applied to copper-tin alloys to which phosphorus has been added. This is the most important of copper-tin alloys. The tin content varies from a fraction of one percent to a maximum of 11 percent. The proportion depends on the physical requirements and shape of the finished product.

Three grades of phosphor bronze—A, C, and D—are available in sheet form. A is a four to five percent tin alloy but C and D contain eight and 10 percent tin, respectively. These alloys are used widely for springs and diaphragms. That's because of their elasticity and resistance to wear and fatigue. Phosphor bronze is also used in valves, discs, and electrical contacts.

MANGANESE BRONZE is a copper-zinc alloy containing aluminum, manganese, iron, and occasionally nickel and tin.

Manganese bronze is exceptionally strong, tough, corrosion-resistant, and easily forged or rolled. It's used in catapults, landing gears, tail skid fittings, and brackets. It can be welded and is machined quite readily.

Of all the copper base alloys, one of the most successful is BERYLLIUM COPPER. It contains approximately 97½ percent copper, 2.15 percent beryllium, and .35 percent nickel.

The most valuable feature of beryllium copper is that it can be worked and formed readily when in the annealed condition, and by heat treatment its strength

can be stepped up almost three times. Tensile strength, for instance, can be increased from 70,000 psi in the soft annealed condition to approximately 200,000 psi.

Its resistance to fatigue, wear, and corrosion makes it very suitable for diaphragms, precision bearings, and

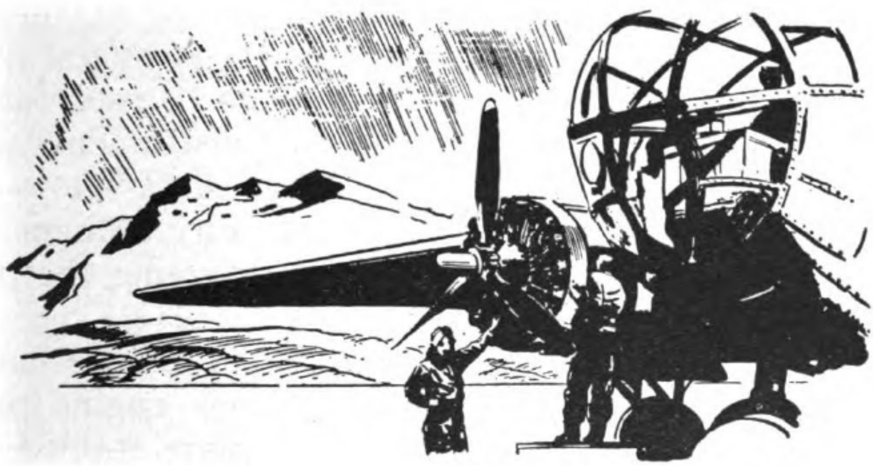


Figure 27.—Copper tubing carries the life blood of the engine.

bushings, ball cages, watch and instrument parts and all types of small machined parts.

MAGNESIUM IS LIGHTEST

Magnesium is a silvery white metal weighing two-thirds as much as aluminum. It is the world's lightest structural metal. Like many other metals,, magnesium does not possess sufficient strength in its pure state for structural uses, but when mixed with such elements as zinc, aluminum, and manganese, the result is an alloy having the HIGHEST STRENGTH-WEIGHT RATIO of any of the commonly used metals.

In the United States, magnesium is produced commercially from the brine of salt wells in Michigan, and on a still larger scale from sea water in the Gulf of Mexico. There is sufficient magnesium chloride in each barrel of sea water to produce about two-thirds of a pound of metallic magnesium. The metal is obtained

from the magnesium chloride through an electric process.

Increased demands in World War II stepped up magnesium production a hundred-fold—from about six million pounds in 1939 to almost 600 million pounds in 1944.

The principal advantage in the use of magnesium for aircraft lies in the fact that it is the strongest metal per pound. It is non-magnetic and can be used for the cases and other parts of navigational instruments without affecting their operation. Magnesium alloys can be machined and welded without difficulty. Magnesium aircraft sections can be built up by riveting the parts together with aluminum rivets.

Prior to World War II, the use of magnesium in aircraft was confined mostly to a few engine parts. Now, the average Navy warplane requires HALF A TON of this new lightweight champion for use in hundreds of important places. SNJ wing panels fabricated entirely from magnesium alloys and weighing 18 percent less than the standard aluminum panels, have flown hundreds of hours with complete satisfaction.

Some of the aircraft parts which have been made from magnesium with a SUBSTANTIAL SAVING in weight are gun fairings, nose wheel doors, flap cover skin, aileron cover skins, main oil tanks, floorings, turrets, fuselage parts, wing tips, engine nacelles, dive brakes, instrument panels, fairings, radio masts, hydraulic fluid tanks, oxygen bottle cases, ducts, pilot seats, ammunition boxes, and rocket tubes.

While magnesium is subject to corrosion, especially when in contact with wood or other metals, satisfactory chemical treatments and protective coatings and paints have been developed for it.

Magnesium powder is highly combustible and is extensively used in the manufacture of incendiary bombs, tracer bullets, and flares. But in solid form magnesium alloy structures do not present a fire hazard.

Magnesium alloys produced in the United States

TABLE VI

COMPOSITIONS AND USES OF MAGNESIUM ALLOYS

Magnesium Alloy	Nominal Composition—Percent				Use
	Al*	Mn*	Zn*	Mg*	
C	9.0	0.1	2.0	Remainder	Sand and permanent mold castings. Heat treatable.
FS—1	3.0	0.3	1.0	Remainder	Extrusions, plate, sheet, and strip.
G	10.0	0.1	.....	Remainder	Permanent mold castings, Heat treatable.
H	6.0	0.2	3.0	Remainder	Sand castings, Heat treatable.
J-1	6.5	0.2	1.0	Remainder	Extrusions, forgings and sheet.
M	.....	1.5	.....	Remainder	Extrusions, forgings, plate, sheet, and strip. Used also for special sand castings.
O-1	8.5	0.2	0.5	Remainder	Extrusions and forgings. Heat treatable.
R	9.0	0.2	0.6	Remainder	Die castings.

*Al—Aluminum Mn—Manganese Zn—Zinc Mg—Magnesium

consist of magnesium alloyed with varying proportions of aluminum, manganese, and zinc. These alloys are designated by a letter of the alphabet, with the figure "1" indicating high purity and maximum corrosion resistance.

A list of the available alloys giving their compositions and typical uses appear in table VI.

Magnesium alloys are produced in a wide variety of forms such as castings, forgings, extrusions, and rolled sheets and plates. All of these forms are used in aircraft manufacture. Intricate shapes can be formed by casting magnesium alloys in sand or permanent molds, or by die casting. These castings combine lightweight solidity with high strength. And they can be heat treated to improve their strength and texture.

Magnesium alloy CASTINGS are used for such aircraft parts as wheels, crankcase sections, rocker box covers, and instrument and engine accessory cases.

Magnesium alloy FORGINGS can be used to good ad-

vantage for highly stressed lightweight parts. Engine pistons, connecting rods, rocker arms, and bell cranks are good examples.

EXTRUSIONS are formed by pressing hot metal through a die. The metal assumes the shape of the die in much the same manner as toothpaste comes from a tube in the shape of the tube opening. Due to their high ductility when hot, magnesium alloys are excellent extrusion metals. They are extruded into an almost unlimited variety of bars, rods, beams, and tubes. Most of the framework of all-metal airplanes is built from extruded sections—sections such as stringers, spars, ribs, and braces.

Magnesium SHEET AND PLATE STOCK is produced in a full range of thicknesses and sizes. Forming and bending operations are usually done hot, and deep draws can be performed in a single operation. Wide bends can be made cold. Magnesium alloy sheets are suitable for such airplane parts as skin covering, fairing, doors and frames, seats, instrument panels, oil tanks, and ammunition boxes. Plate stock can be used for flooring and heavy structural sections.

All of the common fabrication methods can be used for joining magnesium alloy parts. Structural sections are built up from plate and sheet stock by riveting. For this purpose, 56S aluminum alloy rivets are recommended.

Magnesium alloys CAN BE ARC OR GAS WELDED. For gas welding oxyacetylene or oxycarbohydrogen may be used, but the latter is recommended as it provides a cooler flame. In arc welding, an inert gas such as helium is employed to shield the molten metal area. Commercial torches are available for this particular type of welding. Spot welding may also be used in joining sheets or plates.

CHAPTER 4

HEAT TREATING

HOT STEEL

Heat treating means many things. In general, the term covers a series of operations by which metals are heated and cooled while they are still in a SOLID state. In that way certain DESIRED QUALITIES in the metal are obtained.

Heat treating allows you to soften, harden, relieve internal strains, and change the general properties of a metal to suit your needs.

In the heat treating of ferrous metals four main operations—tempering, hardening, normalizing, and annealing—are involved. In general, these processes, except tempering, involve heating the metal to a point slightly above the critical temperature, and cooling it to obtain the desired physical properties. "Critical temperature," in case you're wondering, is the point at which the grain structure of the metal changes.

You can harden ferrous metals by heating them to a point slightly above the critical temperature and rapidly

quenching them in water, oil, or brine. This last depends on what physical properties you want.

Tempering is the process of removing some of the hardness from the steel so that it is more resistant to chipping. This is one process in which the metal is heated to a point BELOW the critical range and then quenched.

Normalizing is also used to relieve strains in metal but should not be confused with tempering. Normalizing removes all strains set up by forging, machining, bending, and welding. You do this by heating the metal to a point slightly above the critical temperature and then allowing the part to cool in STILL AIR FREE FROM ALL DRAFTS.

The annealing process is used to soften metal so that you can fabricate it to whatever shape you want. This would be impossible in the hardened condition. In annealing, you heat the metal to the critical temperature and allow it to cool very slowly either in a furnace or in a box of dry sand which will dissipate the heat slowly.

HARDENING

Heat treatment produces a marked effect upon the grain structure of steel, and it is while passing through the critical temperature range that the steel acquires its hardening power.

When you heat a piece of steel slowly and uniformly beyond a red heat, it will become steadily brighter until a certain temperature is reached. At this point, the rise in temperature halts suddenly. This is because the metal is absorbing enough heat to change it from a soft type structure to a hardened structure. This is marked by the steel becoming slightly darker in color. After this halt the temperature will continue to rise, the steel will continue to increase in brightness, and if cooled quickly will retain its hardness. However if you allow it to cool slowly, it will again pass through a state of change. The cooling rate is stopped momen-

tarily, and the metal will again change from a hard to a soft type structure.

To obtain maximum hardness, you have to raise the temperature of the steel high enough to complete the change—to the upper critical point. You'll find temperatures for the principal types of aircraft steels in table VII. Steel which has been heated to its upper critical point will harden completely if quenched rapidly. In actual heat treating, though, you must heat it from 25° to 50° beyond the critical point to make certain that the core of the piece has been heated thoroughly. WATCH YOUR TEMPERATURE while you're doing it. If the critical range is exceeded by too much, the hardened steel will be coarse-grained and unsatisfactory.

TABLE VII

HEAT TREATMENT FOR STEELS

SAE STEEL	HARDENING TEMPERATURES (°F.)
1025	1575 to 1650
1095	1400 to 1450
2330	1430 to 1500
X4130	1550 to 1650
4140	1525 to 1625
3140	1475 to 1525

SUCCESSFUL HARDENING OF STEEL DEPENDS LARGELY upon—

HEAT CONTROL, to prevent cracking of thick and irregular sections.

THOROUGH AND UNIFORM HEATING through sections to the correct hardening temperature.

CONTROL OF FURNACE AIR, in the case of certain steel parts, to prevent scaling and decarburization.

CORRECT HEAT CAPACITY, consistency, and temperature of the quenching media, to harden adequately and to avoid cracks.

When heating steel, use accurate instruments to check the temperature. If instruments are not available, however, the temperature of the steel can be judged by its color. The temperatures that correspond to various colors are given in table VIII, but here again the accuracy of your results will depend on your experience and on how well your shop is lighted.

TABLE VIII

COLOR CHART FOR STEEL AT VARIOUS TEMPERATURES

Color:	°F.
Faint red	900
Blood red	1,050
Dark cherry	1,075
Medium cherry	1,250
Cherry or full red	1,375
Bright red	1,550
Salmon	1,650
Orange	1,725
Lemon	1,825
Light yellow	1,975
White	2,200
Dazzling white	2,350

Operations such as forging and machining may set up internal strains in steel parts, so it is best to normalize them before trying to harden them.

Steel has a tendency to warp and crack during quenching, because certain parts of it cool more rapidly than others. Whenever cooling is not uniform, internal strains are set up in the metal. These result in warping or cracking, depending on the severity of the strains. Irregularly shaped parts are particularly susceptible to these mishaps, although evenly shaped ones are often similarly affected.

Follow these rules, and you will cut down the warping tendency.

Never throw a metal part into the quenching bath. It will lie on the bottom of the tank and cool faster topside, which will cause it to warp and crack.

MOVE the part slightly while it is in the bath, to destroy the coating of vapor, which might prevent it from cooling rapidly. This juggling act will also help the bath to give off heat more quickly.

QUENCH the parts in such a way that all of them will cool uniformly and with the least possible distortion. Take your cue from the way gear wheels and shafts are quenched. They're handled vertically.

IMMERSE irregular shaped parts in such a way that the largest sections enter the bath first.

What should you use as a quenching agent? Both that and the form of the bath depend largely on the kind of work to be cooled. Provide enough of whatever liquid is used as a medium so that the metal can be quenched without causing any noticeable change in the temperature of the bath. THIS IS PARTICULARLY IMPORTANT where many articles are to be quenched in quick succession.

WATER is used more than any other ingredient in the quenching of steels and in the hardening process. Water used for quenching should be kept at 70° F. If colder than this, it will crack or warp the steel. If warmer, it will not produce the necessary hardness.

USE SALT BRINE where higher heat is necessary. Prepare it by dissolving ordinary salt in water until you have a 10 percent solution.

And what about OIL? It is much slower to act than water is, but its use will greatly reduce the tendency of heated steel to warp or crack. Don't use oil to quench parts made from high carbon steel, unless they're quite thin—the thicker ones won't get hard enough. Use oil, though, whenever and wherever it will give the necessary hardness.

There is an old adage about "pouring oil on the troubled waters." And you probably know of at least one instance where a ship in distress has dropped oil on rough seas to flatten the waves. A film of oil also goes good on water used for quenching, and this type of bath is used occasionally for such articles as milling

cutters. A thin coating of the oil will adhere to steel plunged into the bath and the steel won't cool as quickly, thus reducing the usual tendency of steel to crack because of contraction.

TEMPERING

Steel that has been hardened by rapid cooling from a point slightly above its critical range is often harder than necessary and generally too brittle for most purposes, to say nothing of its being under severe internal strain. In order to relieve the strains and reduce brittleness, the metal is usually tempered. This is carried out in the same types of furnaces as those used for hardening and annealing although less refined methods are sometimes used for tempering small tools.

As in the case of hardening, tempering temperatures may be determined approximately by color. These colors appear only on the surface and are caused by a thin film of oxide that forms on the metal at 450° F. You must brighten the surface of the metal in order to see these tempering colors. When tempering by the color method, an open flame or heated iron plate is used as the heating medium, and although the results are not absolutely accurate, it provides a convenient means

TABLE IX

COLOR CHART FOR VARIOUS TEMPERING TEMPERATURES OF CARBON STEELS

Oxide Color:	°F.
Pale yellow	428
Straw	446
Golden yellow	469
Brown	491
Brown dappled with purple	509
Purple	531
Dark blue	550
Bright blue	567
Pale blue	610

of tempering many small parts. Tempering temperatures and corresponding colors of carbon steels are shown in table IX.

CASE HARDENING

It is often desirable to have a hard, wear-resistant metal surface or "case" over a strong, tough core.

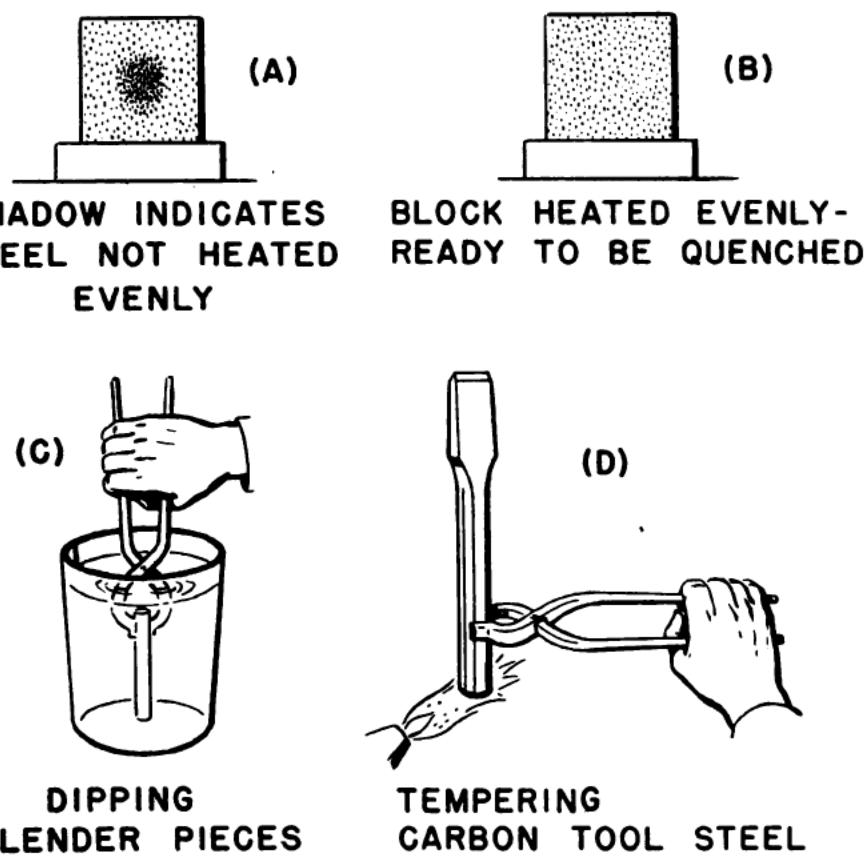


Figure 28.—Steps in hardening and tempering carbon tool steel.

Treatment of this kind is known as CASE HARDENING. While this may be done in several ways, CARBURIZING, CYANIDING, and NITRIDING are the methods used most frequently.

The CARBURIZING process may be applied to both plain carbon and alloy steels, if they are within the low-carbon range. The carburizing steels, listed in table X, are those containing not more than one-fifth of

one percent carbon. The lower the carbon content in the steel, the more readily it will absorb carbon during the carburizing process.

Here's how it works. When steel is heated, the pores of the metal expand and allow it to absorb any gases to which it is exposed. By heating steel while it is in contact with a carbonaceous substance, the carbonic gases given off by this substance will penetrate the steel in an amount proportional to the time exposed and the heat maintained. Thus, if mild or soft steel is heated to 350° F. under these conditions, it will absorb the gas until approximately one-half of one percent of carbon content has accumulated on the surface. But, by increasing the heat to 1,650° F., this same steel can be made to absorb the gas until a 1½ percent carbon content has been attained.

The amount of carbon absorbed and the thickness of the case secured increases with time. But carburizing progresses more slowly as the carbon content increases during the process. The length of time required to produce the desired amount of carburization and depth of hardening will depend upon the composition of the metal, the kind of material used for carburizing, and the temperature to which the metal is subjected. It is obvious that during carburizing carbon will travel slowly from the outside toward the center, and that the proportion of carbon absorbed must, therefore, decrease from the outside to the center.

Metal can be carburized by the use of a solid, a liquid, or a gas.

The first and simplest method consists of soaking the parts at a high temperature while they are in contact with SOLID carbonaceous material, such as wood charcoal, bone charcoal, and charred leather.

LIQUID carburizing consists of immersing the parts in a liquid salt bath, heated to the proper temperature and containing amorphous carbon. The carbon penetrates the pores of the steel, just as it does in the solid method—and you have the case desired.

TABLE X

CARBURIZING HEAT TREATMENT FOR STEELS

SAE steel	Carburizing temperature F.[1]	Grain refinement temperature core [2]
1020	1,650 to 1,700 [a]	1,575 to 1,625.
2320	1,600 to 1,650 [a]	1,500 to 1,550.
2512	1,600 to 1,650 [b]	1,450 to 1,500.
3312	1,600 to 1,650 [b]	1,425 to 1,475.
4615	1,650 to 1,700 [b]	1,450 to 1,500.
6115	1,625 to 1,675 [a]	1,550 to 1,600.

SAE steel	Hardening temperature case [3]	Tempering or drawing temperature °F.
1020	1,400 to 1,425 [a]	350 to 400.
2320	1,350 to 1,400 [b]	350 to 400.
2512	1,300 to 1,350 [b]	300 to 350.
3312	1,350 to 1,400 [b]	300 to 350.
4615	1,335 to 1,400 [b]	300 to 400.
6115	1,450 to 1,500 [a]	350 to 400.

[1] Carburize to desired depth of case, including allowance for grinding.
[a] Cool in air or quench in oil.
[b] Cool in box to 1,000° F., and then in air.
[2] Quench in oil. This treatment may be omitted for 1020 steel on low stressed parts.
[3] Quench.
[a] Water or brine.
[b] boil.

GAS carburizing consists of heating the parts in a pipe-shaped vessel known as a retort and subjecting them to a carbonaceous gas such as carbon monoxide or the common fuel gases. This process is particularly adapted to certain engine parts.

In carburizing, the parts to be treated and the carburizing material are packed together in a sealed steel container to prevent the solid carburizing compound from burning and to retain the carbon monoxide and dioxide gases. Either nichrome boxes, capped pipes of mild steel, or welded mild steel boxes may be used for this purpose. The nichrome boxes are best, as they

withstand oxidation—use the others only as substitutes for nichrome.

The container should be placed so that the heat will circulate entirely around it. The furnace must be brought to the carburizing temperature as quickly as possible and held at this heat from one to 16 hours, depending both upon how deep a "case" you want and the size of the work. After carburizing, the container should be removed and allowed to air-cool, or the parts should be removed from the carburizing compound and quenched in oil or water. Air-cooling is slow, but it reduces warpage and is often advisable. Carburizing temperatures for the various steels are given in table X.

Carburized steel parts are rarely used without subsequent heat treatment. This requires several steps to obtain the best hardness in the case and the best strength and ductility in the core. Grain size of the core and case is refined.

The core is refined by reheating the parts to a point just above the critical temperature of the core steel. Soak them long enough to insure uniform heating, then quench them in oil. The required temperatures are listed in table X.

Because the hardening temperature for the high-carbon case is well below that of the core, it is necessary to reheat the parts to the critical temperature of the case and quench them in oil, to get the desired hardness. A soaking period of 10 minutes is generally sufficient.

A final tempering operation is necessary to relieve the hardening strains produced by the previous treatments. This is managed by heating to the temperatures specified in table X, soaking until uniformly heated, and cooling in still air. If you want extreme hardness, KEEP THE TEMPERATURE at the lower limit of the range.

In CYANIDING, steel parts are surface-hardened by heating while in contact with a cyanide salt and then quenched. Only a thin case is secured by this method

and it is seldom used in aircraft construction or repair. It is, however, a rapid and economical method of case hardening and may be used sometimes for relatively unimportant parts.

The work to be hardened should first be heated to 750° F., and immersed in a bath of molten sodium or potassium cyanide for 10 to 15 minutes. The steel should be absolutely dry before immersion. Otherwise, look out for an explosion. The cyanide bath should be kept at a temperature of 1,500° to 1,600° F. Immediately after removal from the bath, the parts are

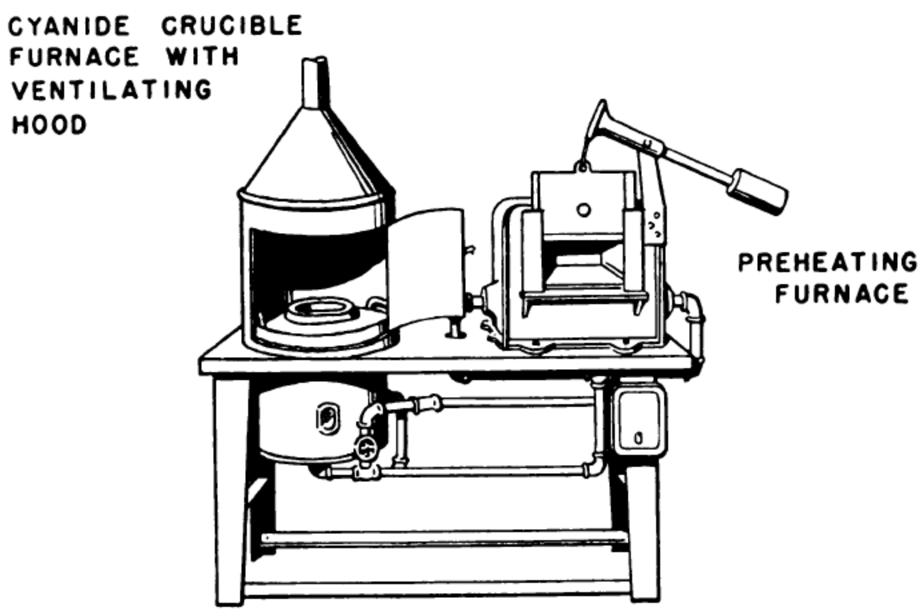


Figure 29.—Case hardening furnace.

quenched in water. The case thus obtained is caused principally by the formation of carbides on the surface of the steel.

Use a closed vessel for this work, or it may be your last job. Cyanide vapors are VERY POISONOUS.

NITRIDING is a better method of case hardening than is carburizing, because it produces a harder case. Many engine parts, such as cylinder barrels and gears, may be treated in this way. Nitriding should be used only on certain steel alloys which contain a substantial amount of aluminum.

The nitriding process involves soaking the parts in anhydrous ammonia at a temperature below the critical point of the steel. During the soaking period, the aluminum and iron combine with the nitrogen of the ammonia to produce iron nitrides in the surface of the metal. Warpage of work during nitriding can be reduced by stress relief annealing before you begin nitrid-

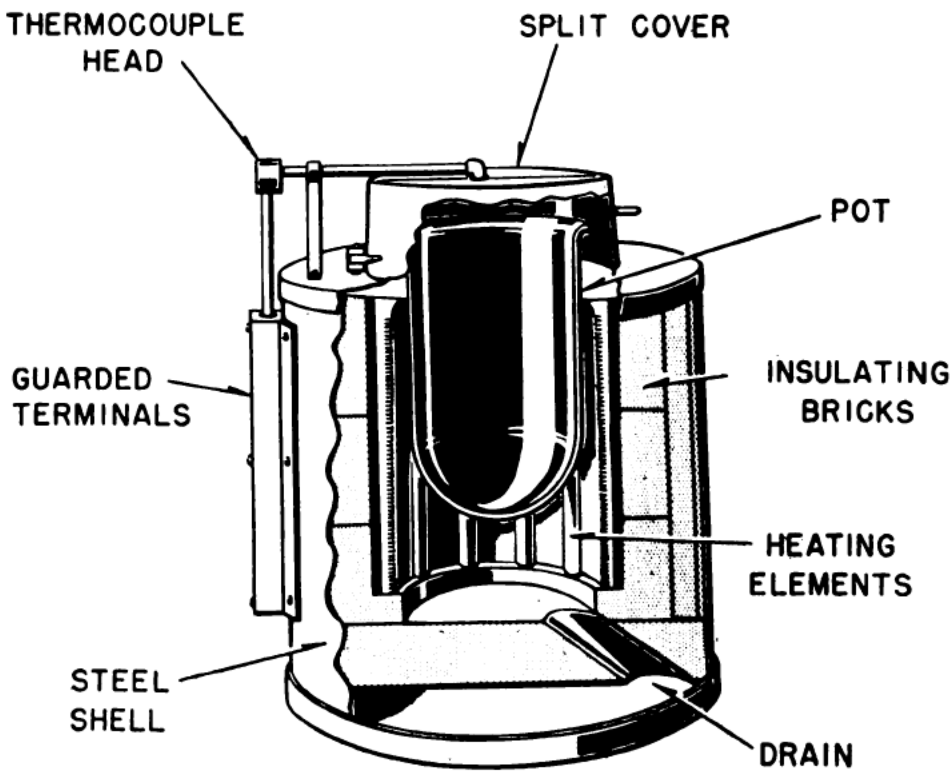


Figure 30.—Salt bath type of heat-treating furnace.

ing operations, and by exposure to nitrogen at temperatures no higher than 1,000° F. Expansion, or growth of the work is also reduced, but cannot be eliminated entirely. Some parts may require special allowance in some of their dimensions to take care of growth.

Nitralloy is a typical nitriding steel. The temperature required for nitriding is 950° F., and the soaking period is from 48 to 72 hours. An air-tight container must be used, and it should be provided with a fan to produce good circulation and an even temperature

throughout. Quenching is not required, and the parts may be allowed to air-cool.

NORMALIZING

NORMALIZING involves a slightly different heat treatment, but is classed as a form of annealing. This process removes all strains caused by machining, forging, bending, and welding. Normalizing can be done only with a good furnace, where air and temperatures can be regulated closely and kept on an even keel throughout the entire operation.

Assume that you are normalizing steel. Put it in the furnace and heat it beyond its critical temperature. Hold it there long enough for the heat to penetrate to the center of the section, then remove it from the furnace and cool it in still air. Try to keep out drafts, for they will cause uneven cooling, which will again set up strains in the metal. Don't soak the steel too long at high temperatures, or the grain structure will enlarge. How long is "too long?" Well, the length of time required depends upon the volume of metal being treated.

ANNEALING

The most important step in annealing is to raise the temperature of a metal to the critical point—any existing hardness will then disappear. Also, strains set up by heat treatment will be eliminated when steel is heated to the critical point and then restored to its lowest hardness by slow cooling.

In annealing, NEVER heat steel more than 50° to 70° F. above the critical point. When large parts are annealed, allow enough time for the metal to become well heated.

Steel is usually annealed for two reasons—to increase its ductility by reducing hardness and brittleness and to refine the crystalline structure and remove stresses. Thus, steel which has been cold-worked is

generally annealed to increase its ductibility. Cold-drawn wire, however, is not annealed when very high yield point and tensile strength are desired and relatively low ductility is permissible.

Suppose that the part to be annealed has been heated to the proper temperature. It must be cooled slowly. There are several ways to do this, depending on the metal and the degree of softness required, but PACKING and FURNACE COOLING are the methods used most often. In the first instance, you bury the part in some substance that doesn't conduct heat readily. A metal box containing slaked lime, ashes, or powdered charcoal is fine for this, but the material must be kept perfectly dry. Furnace cooling is just what you thought it was—letting the furnace and the part cool off together.

CHROME-MOLYBDENUM—AN EXAMPLE

You don't want to be dragged through descriptions of heat treatment processes for each and every one of the aircraft steels. So look at a few typical heat treatments for the well-known chrome-molybdenum steel (SAE 4130 and 4135) and rely on a table of times and temperatures for the others.

For ANNEALING, hold the furnace temperature below 1,100° F. when the parts are inserted, then increase it gradually to between 1,600° and 1,700° F. After holding the parts at this temperature long enough for them to become fully heated, shut the furnace down and allow them to cool to 1,100° F. Then remove them and allow them to cool in still air. The ultimate strength of the fully annealed steel is approximately 78,000 psi.

In NORMALIZING, the parts are heated as described for annealing but are removed from the furnace directly after the soaking period, and allowed to cool in still air. The ultimate strength secured by this process is approximately 90,000 psi.

HARDENING is accomplished by inserting the parts in a furnace which has been preheated to not more

than 1,100° F. The temperature should then be raised gradually to between 1,550° and 1,650° F. Time and temperature will depend upon such factors as the thickness, size, and shape of the parts to be hardened. Heat parts less than one-fourth-inch thick only to the lower limit of the range. After the soaking period, remove the parts and quench them in oil.

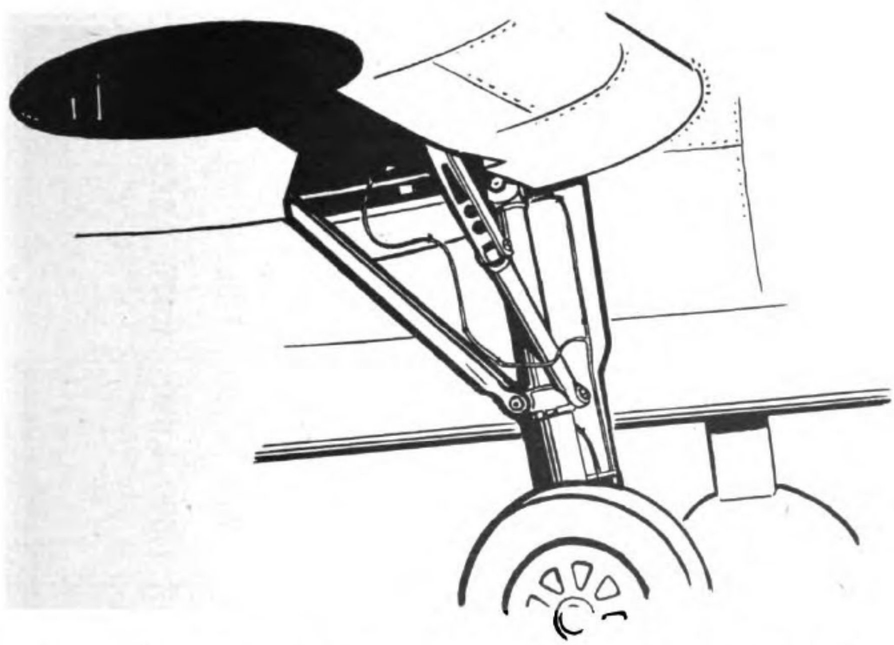


Figure 31.—Retractable landing gear. Heat-treated chrome molybdenum tubing.

Hardened chrome-moly parts may be TEMPERED for various ultimate tensile strengths. In any event, the furnace temperature should be below that of the tempering temperature when the parts are inserted, then gradually brought to the required heat. Always cool parts in still air.

TEMPERING TEMPERATURE °F.:	ULTIMATE STRENGTH PSI
1,075	125,000
1,000	150,000
950	180,000
650	200,000

Because of its higher carbon content, HIGH CARBON

TABLE XI

HEAT TREATMENT PROCEDURE FOR STRUCTURAL STEELS

Steel No.	Temperatures			Quenching medium	Temper-ing tem-peratures	Ultimate tensile strength
	Normalizing air cool	Annealing	Hardening			
	° F.	° F.	° F.	[1]	° F.	Psi
SAE 1025	1,575–1,650	1,575–1,650	1,575–1,650	Water or brine.	[2]	
SAE 2330	1,500–1,600	1,500–1,600	1,430–1,500	Oil	1,050	100,000
					950	125,000
					800	150,000
SAE 3140	1,550–1,650	1,550–1,650	1,475–1,525	Oil	1,050	100,000
					950	150,000
					800	180,000
SAE 4340	[3] 1,500–1,600	1,500–1,600	1,475–1,525	Oil	1,200	125,000
					1,050	150,000
					950	180,000
					850	200,000

Steel No.	Temperatures			Quenching medium	Temper-ing tem-peratures	Ultimate tensile strength
	Normalizing air cool	Annealing	Hardening			
SAE 6135	1,600–1,700	1,600–1,700	1,575–1,625	Oil	950	150,000
					800	180,000
					750	200,000
SAE 6150	1,600–1,700	1,600–1,700	1,575–1,625	Oil	1,000	150,000
					850	180,000
					800	200,000
Corrosion resisting (16–2).[4]						
Corrosion resisting (18–8).	1,600–1,650	1,700–2,050				
Silicon chromium (for springs).			1,700–1,725	Oil	(5)	

[1] Water used for quenching shall not exceed 65° F. Oil used for quenching shall be within the temperature range of 80°–150° F.
[2] Doesn't harden enough to require tempering, except for thin sections.
[3] Furnace cooling.
[4] Heat treatment of steel, Spec. AN–QQ–S–770 recommends that, prior to tempering, corrosion-resisting (16Cr–2Ni) steel be quenched in oil from a temperature of 1,875°–1,900° F., after a soaking period of one-half hour at this temperature.. To obtain a tensile strength of 115,000 psi, the tempering temperature should be approximately 1,200° F. and for 175,000 psi, approximately 525° F. A holding time of about 2 hours is recommended at these temperatures. Tempering temperatures between 700 and 1,100° F. will not be approved.
[5] Draw, at approximately 800° F. and cool in air for Rockwell hardness of C–50.

CHROME-MOLYBDENUM STEEL (SAE 4140) responds more readily to heat treatment than SAE 4130 does. This steel is used extensively for heavy parts that have been machined from bar or forging stock. The heat treatment for it is identically the same as that required for 4130 except for the temperatures used.

Annealing and normalizing are carried out at a temperature of between 1,600° and 1,700° F.

Hardening is accomplished at a temperature of from 1,525° to 1,625° F. The hardness will be inversely proportional to the tempering temperature—that is, the higher the temperature, the softer or less hard the metal will be.

Tempering SAE 4140 for aircraft requirements can be accomplished at any one of three different temperatures, each of which will produce a different ultimate strength.

Tempering Temperature °F.:	Ultimate Strength psi
1,250	100,000
1,100	125,000
650	200,000

SAE 4130 generally is obtained from the manufacturer in the normalized condition. This is satisfactory for the majority of parts which are to be welded, especially where subsequent heat treatment is not feasible.

You may find normalized sheet metal difficult to bend or form. In this case, anneal it to make forming operations easier. Where annealed, formed sheet metal is used in a built-up welded assembly and you had better see to it that all the parts are annealed instead of trying to weld annealed and unannealed parts together.

On the other hand, you will find this kind of steel used most often in fabricated parts which have previously received some type of heat treatment. YOU MUST KNOW the exact condition that the steel is in, because such work as welding or bending will affect unfavorably physical properties obtained by heat treatment. If you

have facilities for the right kind of heat treatment, your safest course will be to anneal the parts, carry out any necessary machining, bending, or welding operations, and then reheat-treat it, according to the original specifications.

IT'S DIFFERENT FOR ALUMINUM

Heat treatment of aluminum alloys, as the term is commonly used, covers the processes which you use to

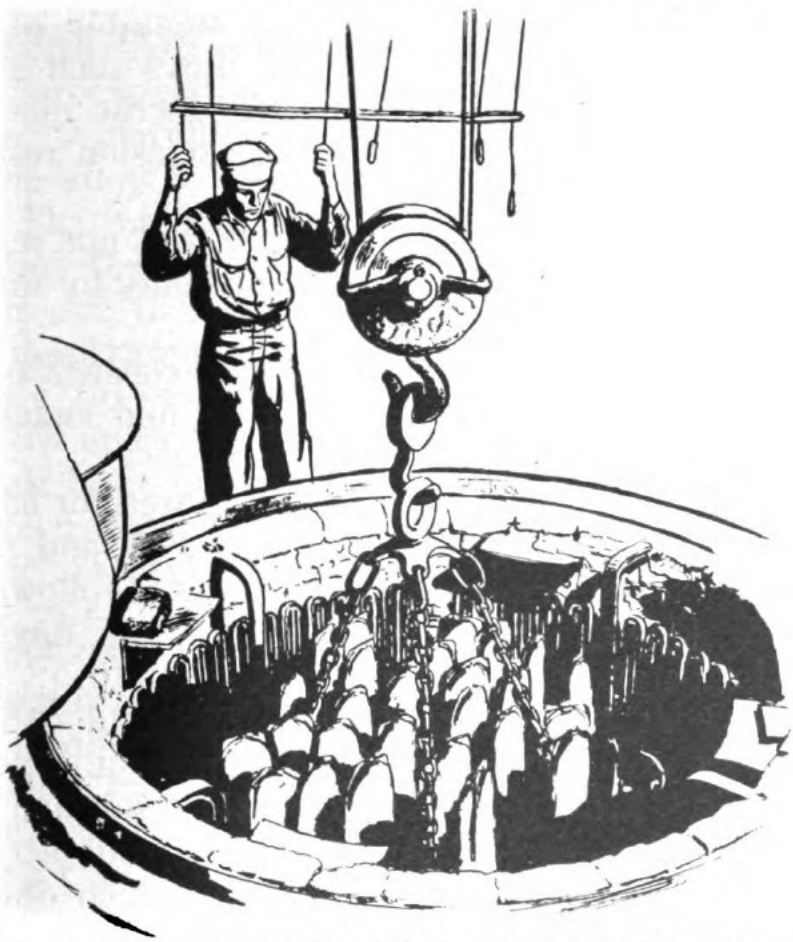


Figure 32.—Lowering forged aluminum propeller blades into electric-heat treating furnace.

change the mechanical properties of the alloy. The use of heat treatment on aluminum alloys is quite different from that employed for steels.

In aluminum alloys there is only one grain or crystalline structure of the aluminum and this structure

DOES NOT CHANGE with heat treatment. In the case of steel, the grain structure changes with heat treatment. When aluminum alloys are heat treated and reach their critical temperature, the alloying materials are distributed evenly within the metal. This gives it an increase in hardness, but the grain structure of the aluminum itself remains the same. The copper, manganese, magnesium, and other elements are merely SPREAD OUT among the aluminum grains to give it additional strength.

Aluminum alloys are either heat treatable or non-heat treatable. Heat treatment of alloys such as 17S and 24S will change them from soft, ductile metals to hard metal with good strength and corrosion resistant properties.

But alloys such as 2S, 3S, and 52S will not respond to heat treatment and can be hardened only by forming and cold working.

Heat treatment of aluminum alloys consists of two processes, SOLUTION HEAT TREATMENT, and PRECIPITATION HEAT TREATMENT.

You find solution heat treatment required for hardening aluminum alloys 17S, 24S, Alclad 17S, and Alclad 24S. The actual heat treatment process is followed by a period of natural aging which takes four days and results in the alloy achieving its full strength.

In the heat treatment of alloys 53S and 61S, full strength is not realized until they are subjected to precipitation heat treatment following solution heat treatment. Precipitation heat treatment subjects 53S and 61S to an artificial aging process which develops their maximum strength.

In solution heat treatment there are three main steps to follow. That's also the case, you remember, in hardening steel. Principally, the steps are heating, soaking, and quenching the metal. The temperatures involved for aluminum alloys are much lower than those for steel. In heating, it is necessary to hold the alloy within a plus or minus 10° of the temperature

specified if you want to get the proper results. Here are temperatures for some of the commonly used alloys.

17S & A17S........	940° F. plus or minus 10° F.
24S	920° F. plus or minus 10° F.
53S & 61S.........	970° F. plus or minus 10° F.

If your temperature is too low you won't get the proper hardness. If it's too high, there's a possibility that the metal will blister. And then, too, the corrosion resistance is greatly impaired.

You use two methods for heating aluminum alloys—the AIR FURNACE and the SALT BATH.

The salt bath consists of a tank holding a solution of 50 percent sodium nitrate and 50 percent potassium nitrate. When these salts are heated they become liquid and the alloy to be treated is submerged in the solution. The main disadvantage of the salt bath is the distortion that comes to material immersed in the bath. This is due to the rapid change in temperature. Another disadvantage is that the salt must be washed off. Here's a tip—never heat treat complicated parts in a salt bath unless they can be readily washed off.

A salt bath, however, has an advantage over the air furnace because it provides a more uniform and constant temperature.

One thing you should never attempt is to heat treat 17S and 24S at the same time by setting the temperature control at 930° F. Theoretically, both 17S and 24S alloy COULD be heat treated at 930°. But no pyrometer furnace control is perfect enough to hold a constant temperature without variation. That's why it's never wise to double-up on heat treatments.

Except on Alclad material, the time of soaking an aluminum alloy at an elevated temperature is not so important. In the case of Alclad, the heating time should be as short as possible. The reason for this is that the copper in the alloy tends to go into solution with the pure aluminum coating, thereby cutting down on corrosion resistance. Table XII shows soaking times for aluminum alloys.

TABLE XII

SOAKING TIMES FOR ALUMINUM ALLOYS

Material thickness (inches)	Salt Bath		Air Furnace	
	Maximum time (minutes)	Max. time on Alclad	Min. time (minutes)	Max. time on Alclad
Up to .020	5	15	5	15
.021 to .032	10	20	10	20
.033 to ,064	15	25	20	30
.065 to .125	20	30	30	40
.126 to .250	25	35	50	70
.251 to .500	30	40	90	110

If you want to get correct heat treatment of aluminum alloys, quenching must be done immediately after removal of the metal from the salt bath or air furnace. Dilly-dally even a few seconds between furnace and quench tank and you'll decrease the strength and lower the corrosion resistant properties of your alloy.

Quenching should be done in a tank of cold water, preferably at a temperature below 50° F. NEVER QUENCH MATERIAL IN WATER WITH A TEMPERATURE ABOVE 90° F. It's best to have running water in the tank so that the temperature will not build up while parts are being quenched.

Aluminum, the same as steel, has two processes of annealing. These are FULL ANNEAL and PARTIAL ANNEAL. Full anneal completely softens both heat treatable and non-heat treatable alloys.

Heating for full anneal is usually done with an air furnace at the temperatures listed below.

ALLOYS	TEMPERATURES
2S & 52S	650° F.
3S	750° F.
All heat treatable alloys	750° to 800° F.

Full annealing of alloys 2S, 3S, and 52S is practically instantaneous. All you need to do is get the material to the required temperature. Although the cooling rate is not of major importance, it's good to remember that if the cooling is too rapid, the material will warp.

In heat treatable alloys, however, annealing does not

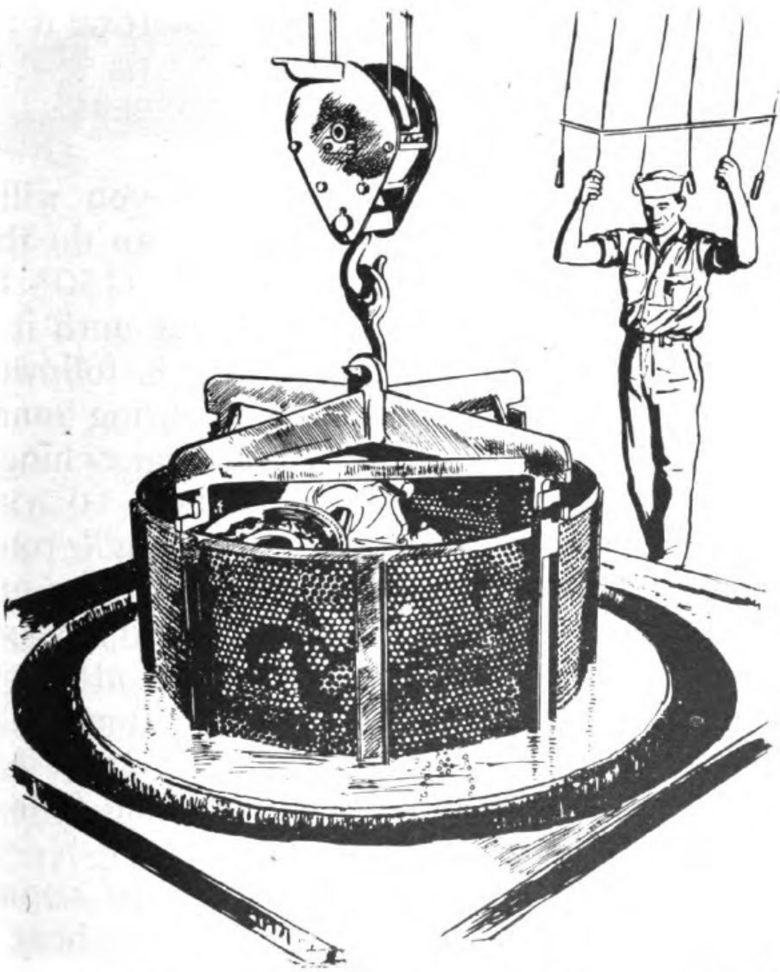


Figure 33.—Lowering aluminum forgings into quenching tank after heat treatment.

take place as rapidly as in non-heat treatable alloys. You should hold the temperature on heat treatable alloys for two hours, then reduce it 50° an hour until the material is at 500° F. It can then be removed. The time for cooling to room temperature is relatively unimportant.

Partial anneal is usually used on heat treated material to remove the effects of strain caused by cold working.

Heat the material to a temperature of 630° to 660° F. in an air furnace. Then soak it there for a period of about two hours. The rate of cooling is unimportant provided the material is not heated above 660°. Whenever you use partial anneal on a heat treatable alloy, give it a solution heat treatment before putting it to use.

SPECIAL ATTENTION FOR COPPERS

In general, the only heat treatment you will give copper will be that of annealing. You can do this by heating the copper in an air furnace to 1150° F. for five minutes or by heating it with a torch until it turns a dull red. Either of these operations is followed by quenching in water. Copper will scale during annealing and must be cleaned by pickling after quenching.

A SALT BATH SHOULD NEVER BE USED TO ANNEAL COPPER. If you follow that practice, you'll run into plenty of trouble trying to get rid of all traces of salt.

The alloys of copper are so numerous and have such a wide variety of alloying elements that no attempt will be made here to describe their heat treatment. If the occasion arises where you have to heat treat any of these alloys, consult a metals handbook and follow the instructions given for the particular metal.

Even though a great many alloys may LOOK like copper and work like it, NEVER attempt to heat treat them in the way just described for pure copper. Heat treatment for alloys varies as much as the alloys themselves.

CHAPTER 5

WORKING PROCESSES

WHAT THEY ARE

When it isn't cast the way you want it, metal is formed into desired shapes by MECHANICAL working processes. These processes fall into two general classifications—HOT and COLD.

Technically speaking, the term HOT WORKING applies to those mechanical working processes that are performed while the metal is ABOVE its critical range in temperature. COLD WORKING applies to all such operations carried out with the metal BELOW its critical range. You'll recall that the critical range varies with the different metals.

But from a practical standpoint, the word "cold" in "cold working" means ORDINARY ROOM TEMPERATURE.

When you cold work metals you don't wind up with the errors that come in shrinkage when metals are heated and cooled. And you don't get the scale formations on the surface which come from hot working. You get a much more compact and better metal by cold working. The strength and hardness as well as the elastic limit is INCREASED. However, the ductility DE-

CREASES. Since this makes the metal much more brittle, you'll have to heat it from time to time during some operations to remove the undesirable effects of the working.

While there are several cold working processes, the two with which you will be principally concerned are COLD ROLLING and COLD DRAWING. These give the metals desirable properties which cannot be obtained by hot working.

COLD ROLLING

As mentioned previously, cold rolling usually refers to the working of metal at room temperature. First, you take materials that have been hot rolled to the approximate size you'll want from cold rolling. You PICKLE these in an acid to remove the scale. Then pass them through chilled finishing rolls. This gives a smooth surface and also brings them to accurate dimensions.

The principal forms of cold rolled stock are SHEET, BAR, and RODS. They are obtainable in other forms, but these are the most widely used.

COLD DRAWING

Cold drawing is used in the manufacture of seamless tubing, wire, streamlined tie rods, etc.

Wire is manufactured from hot rolled rods of various diameters. These rods are pickled in acid to remove the scale and dipped in LIME WATER and then dried in a steam room where they remain until time for drawing. You'll find that the lime coating adhering to the metal serves as a lubricant during the drawing operations.

The size of the rod used for drawing depends upon the diameter you want in the finished wire. To reduce the rod to the desired size wire, it is drawn cold through a die in much the same way that extrusions are made.

One end of the rod is filed or hammered to a point and slipped through the opening of the die, where it is

gripped by the jaws of the draw head and then pulled through the die. This series of operations is accomplished by the use of a mechanism known as the draw bench.

As you have to reduce the rod gradually to the desired size, it is necessary to draw the wire through successively smaller dies until the correct dimensions are obtained.

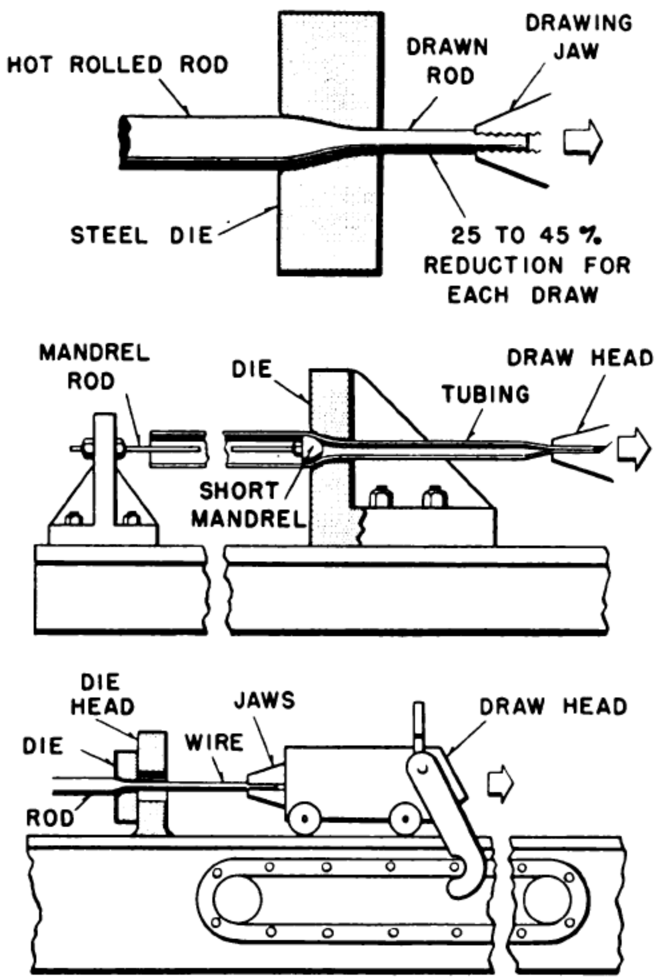


Figure 34.—Top, method of cold drawing wire. Center, cold drawing seamless steel tubing. Bottom, working principles of the draw bench.

Because each of these drawings reduces the ductility of the wire, it must be annealed from time to time before further drawing can be made.

Although cold drawing reduces the ductility of wire, it increases the tensile strength enormously. Piano

wire, for example, may be cold drawn to small diameters having a tensile strength of 300,000 psi!

You can decrease its cross-sectional area by as much as 30 percent on each draw. By proper selection of the amount of reduction to be made in each draw and the number of draws to be made after annealing, you can obtain any reasonable strength of wire.

Manufacture of seamless steel aircraft tubing presents some knotty problems—it must be accurate in outside diameter, and its thin wall must be uniform in thickness and free from defects. All such tubing is finished to size by cold-drawing. Any one of three like processes may be used. The chief difference in them lies in the method of controlling the inside diameter of the tube.

Briefly, the tubing is cold-drawn through a ring-shaped die, with a mandrel, or metal bar inside the tubing to support it while the drawing operations are under way. This forces the metal to flow between the die and the mandrel, and affords a means of controlling the wall thickness and the outside and inside diameters. The tube is drawn through dies and over mandrels of varying sizes until reduced to the finished dimensions.

As in any cold working operation, the metal should be free from scale, and so is pickled before it is cold drawn. The sectional area is reduced from 15 percent to 25 percent by each draw so that it is usually necessary to anneal and pickle the tube AFTER EACH OPERATION to soften it sufficiently for the next one. Sometimes, as many as 10 draws are necessary to obtain a tube of the required diameter and wall thickness. Special lubricants are used to reduce the friction between the mandrel, tube, and die.

HOT ROLLING

Among the many different types of hot working processes, ROLLING, FORGING, PRESSING, and EXTRUDING are the most important.

Steel is rolled by passing hot slabs of metal through large rolls, thereby forming them into sheets like the sheet stock with which you work. There are a good many shapes which are hot rolled, but this material is not as satisfactory as cold worked steel. Hot rolled steel is not as accurate in dimensions as cold rolled. Neither are its machining properties as good. Try cutting threads on a piece of hot rolled steel rod and then on a piece of cold rolled steel. You'll see the difference.

FORGING

Since hot rolled steel has its limitations as to shape and as its physical properties are low in a good many respects, the metal is forged to gain many desired

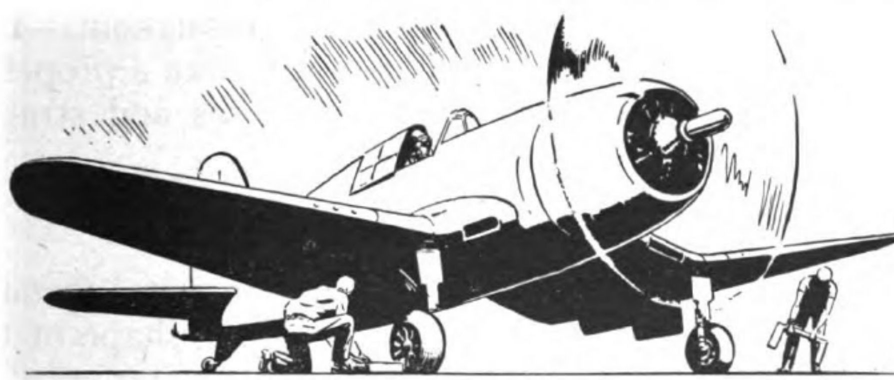


Figure 35.—Propellers are drop forged.

properties. It's a way, too, to produce the shape you want. Forging is the process of heating and hammering metal to a wanted shape. Forging can be done in one of two ways—by HAND HAMMERING and by mechanical hammering known as DROP FORGING. PRESSING is actually a form of mechanical forging. The process is used for relatively large and heavy sections of metal and takes its name from the enormous machines with which it is done.

The actual forging you'll be doing is hand forging such as making up chisels and punches or small hand tools of some type.

Chrome moly and chrome-nickel-molybdenum steels are used extensively for drop forged aircraft parts and fittings. Fittings for landing gears, strut ends, and engine mounts are usually drop forged, machined, and heat treated. This gives THE BEST in strong, dependable steel parts.

Some of the aluminum alloys are successfully drop forged into light, strong fittings and into some structural parts. Aluminum alloys which are especially suited to forging include 17ST, 25ST, and A51ST. Alloy 17ST is used for small structural fittings, while 25ST is used for propeller blades. Both the 25ST and A51ST are used for forged engine parts, such as pistons and various case assemblies.

You'll find these forgings far superior to castings. They are free from blowholes, gas cavities, and the structure of the metal is UNIFORM throughout. You can see the importance of this in a part like a propeller blade which is subjected to high stresses and strains.

EXTRUDING

The extrusion process involves forcing metal through an opening in a die. The metal takes the shape of the

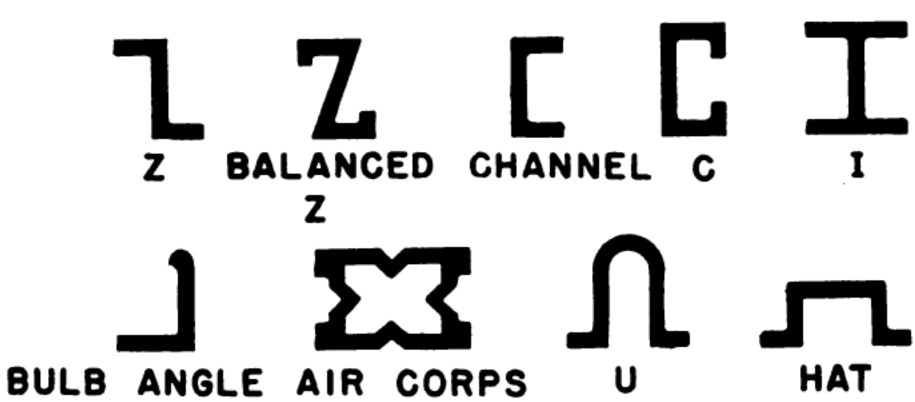


Figure 36.—Extruded sections.

die. Some metals, such as lead, tin, and aluminum may be extruded cold, but generally they are heated before

being extruded. Many structural parts, such as stringers, are formed by the extrusion process. A cylinder of aluminum is heated to around 750° to 850° F. and is then forced through the opening of a die by a hydraulic ram. The temperature and pressure required vary with the alloys being extruded. Some pressures will run as high as 4,000 pounds.

Among the extruded aluminum alloys used in aircraft, 2S, 3S, 17S, and 24S are the most common.

Figure 36 shows some of the more common extruded sections.

CHAPTER 6

PROTECTION FOR METALS

THE UNSEEN ENEMY

Enemy bullets can cause visible damage to an airplane.

But even more dangerous than bullet damage is CORROSION damage to metal parts. It's that way because corrosion can't always be seen. In many cases it's an INVISIBLE ENEMY. And when it's invisible it's because of one of two reasons—construction which conceals the corroded part, or corrosion under the surface of the metal.

Among several definitions, Webster says that to corrode is "to eat away as if by gnawing; to wear away gradually; to consume; to impair." Then he lists as a synonym the word "waste."

It's true that corrosion is all of those things, and more. But the two to keep especially in mind are IMPAIR and WASTE. Corrosion is a waste of precious metals. And if you don't detect it early and make repairs, you are impairing the chances for long life of any and all persons who may be assigned to the craft which you're inspecting and supposedly keeping shipshape.

So any Aviation Metalsmith worth his chow uses every precaution in the book to avoid corrosion.

The corrosion you most frequently encounter is exterior or surface corrosion. The first warning of it is the appearance of a dirty, dust-like, white powder which blotches the surface of the metal. The blotching gets worse as the deterioration increases and the metal will finally break up.

Another type of corrosion which is less frequent is called inter-crystalline (intergranular) corrosion. This is an unseen enemy. It means that the crystalline or GRAIN STRUCTURE of the metal has broken down due, possibly, to the amounts of silicon or magnesium the metal contains. Usually, you can't see the breakdown without a microscope. But it shows up rapidly in metal which becomes quite brittle and weak.

You can't stop or retard grain structure corrosion. When such deterioration is discovered, the part should be replaced without delay.

Another type of corrosion you'll need to watch for and guard against is that caused by the contact of dissimilar metals—metals such as aluminum alloy and steel or aluminum and cadmium. Heat treatable and non-heat treatable alloys are considered dissimilar.

When dissimilar metals are joined in direct contact, an electrolytic action takes place and the metal with the higher electropotential corrodes. Aluminum and its alloys possess a comparatively high electropotential and are susceptible to corrosion when contacting other common aircraft metals.

To prevent surface corrosion of all kinds of aircraft metals, various kinds of finishes are applied as protection. Surface finishes are also used to add color and beauty to increase resistance to wear, but in Naval Aviation their primary and most important purpose is PROTECTION. The danger of structural weakness caused by corrosion in airplanes operating in and around salt water, for instance, is magnified many times.

The kind of metal on which the finish is to be applied

will determine to a large extent the type of finish that is employed. On metals such as steel and its alloys, several different kinds of finishes may be used, while on magnesium only a limited number of protective coatings can be applied.

CLEAN IT FIRST

No matter what kind of protective coating is applied to a metal, the metal must be CLEANED before finishing. If the metal is not clean, the proper bond between the

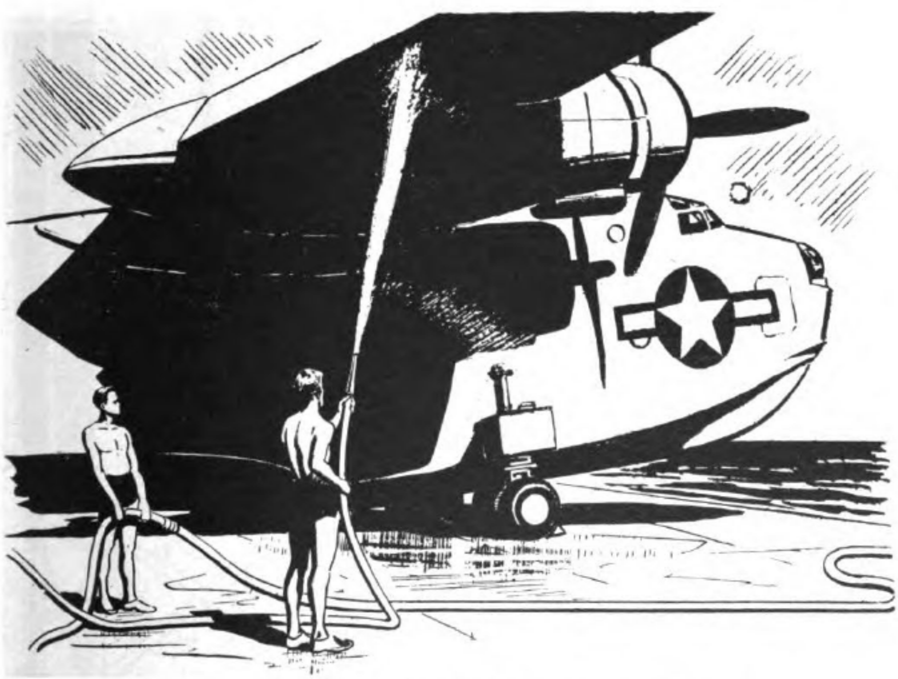


Figure 37.—Salt deposits invite corrosion.

metal surface and the finish cannot be secured. The surface must be absolutely free of all grease, wax, dirt, oxides, and any other foreign material.

Cleaning may be done by either mechanical or chemical means. Although some finishes demand a special type of operation, the procedures that follow are applicable to most finishing work.

SANDBLASTING is a mechanical means of cleaning. It involves the use of a stream of sharp sand or steel grit

driven from a nozzle by air pressure. Sandblasting allows a new finish which is to be applied to adhere well.

The three most commonly used types of sandblasting equipment are portable sandblasting machines, sandblasting cabinets, and sandblasting rooms. The portable set is used for sanding corroded parts on an airplane.

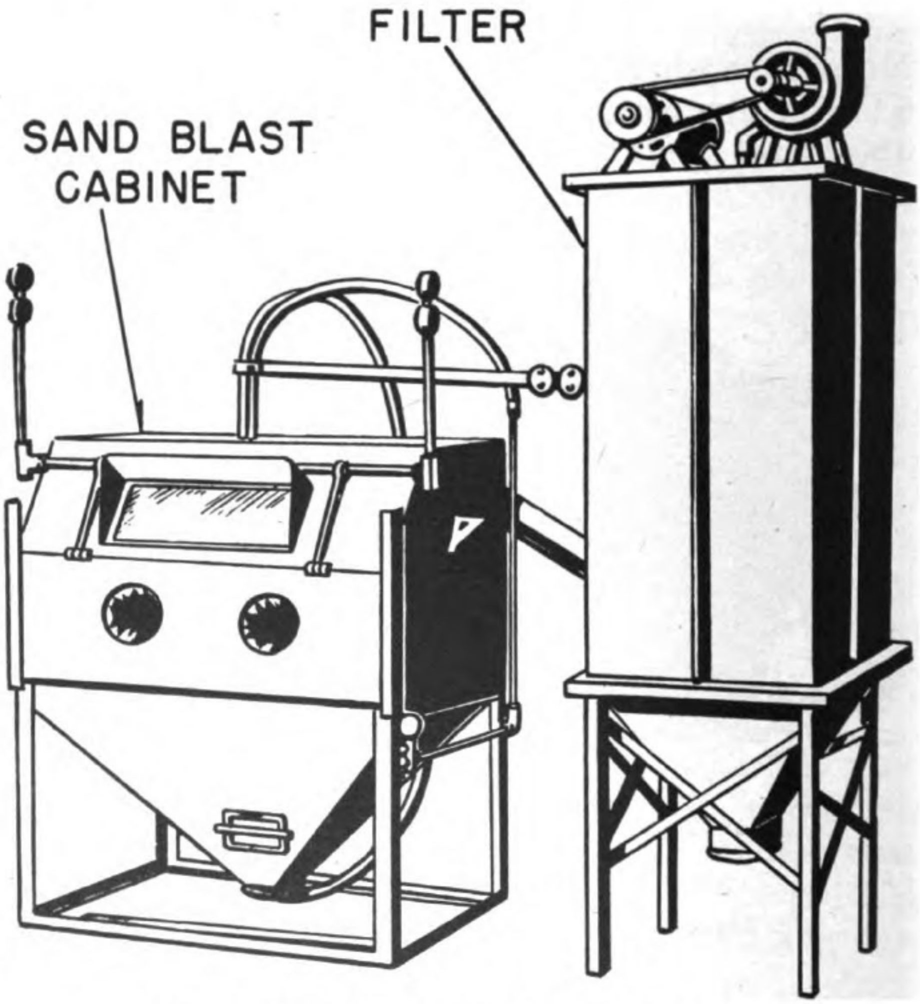


Figure 38.—Sand blast cabinet and filter.

The sandblast nozzle should be held from six to eight inches from the work and at right angles to it. Care should be taken so that highly-stressed parts of thin sections are not sandblasted too much, thereby affecting their physical properties.

You won't sandblast aluminum alloy surfaces very often. That's because sandblasting increases their soft-

ness, and thinness, and decreases their ductility. If the process is used on aluminum, the abrasive should be fine and the air pressure low. The nozzle should be held 18 to 24 inches away from the surface.

Any aircraft part that has been sandblasted should be cleaned with a chemical treatment before being given a protective finish.

SCRAPING, FILING, BUFFING, and POLISHING are other means of mechanical cleaning. Welding scales or oxides, old coats of paint, and heavy accumulations of rust, grease, and dirt may be partially removed by scraping. This may at times be followed by filing or brushing with a wire brush.

A machine wire buffer can remove a considerable amount of foreign material from a metal surface. And if you want to be sure the metal is properly cleaned, it's best to buff the surfaces until you get a high luster. Power driven buffer wheels are the best for that.

Among the common chemical cleaning processes are organic solvents, pickling, and electro cleaning.

ORGANIC SOLVENTS such as benzol, carbon tetrachloride, and naphtha may be used to remove grease and oil. Parts cleaned by this method should be rinsed thoroughly before finishing.

PICKLING is a process of dipping a metal article in nitric acid. It is used to remove scale and oxides from the surface. The kind and strength of the solution will depend upon the kind of metal, the type of metal finish you want, and the type of scale or oxide to be removed. After pickling, metal should be thoroughly rinsed with cold water.

ELECTRO CLEANING is occasionally used to remove grease and dirt. In this process, you suspend the metal in a hot alkaline solution containing a small amount of potassium cyanide. An electric current is passed through the solution in a manner similar to that used in electroplating. The material to be cleaned acts as the anode and the tank as the cathode.

All cleaned parts should be given the desired protec-

tive coating AS SOON AS POSSIBLE AFTER CLEANING. Otherwise, foreign materials will gather and new oxides will form. The maximum allowable time between cleaning and finishing operations depends on climatic conditions, the type of metal, and the type of finish. In every case the metal should be as clean as possible at the time of finishing.

Just as there are several ways of cleaning metal, there are also many kinds of corrosion preventives to be used in the finishing process, which may be used on all types of metals.

Steels may be finished by electroplating, metallizing,

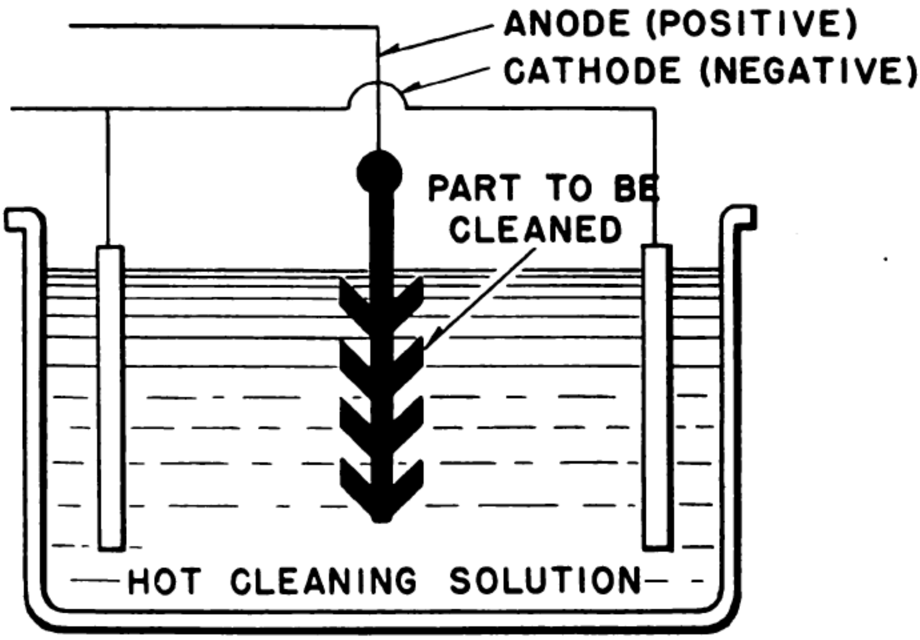


Figure 39.—Electro cleaning.

Parkerizing, priming, and painting. Aluminum adapts itself readily to anodizing, metallizing, priming, and some chemical treatments, while several other chemical finishes are most desirable for magnesium. When a chemical protective coating has been applied, the surface is frequently finished by applying a primer followed by paint or lacquer.

Paralketone, paints, lacquers, and zinc chromate primer may also be used as additional protection for

metals already given other corrosion preventive coatings. And in an emergency any one of them may be used alone or in combination to help prevent corrosion.

ZINC CHROMATE PRIMER

Zinc chromate primer has many uses. It's a corrosion preventive, a base for paint, an interior finish, and a lacquer sealer all in one. It is the most commonly specified primer used in the aircraft industry for both production and repair work. It may be used on aluminum, aluminum alloys, steel, and magnesium.

Zinc chromate primer is made of zinc yellow, synthetic resins, stabilizers, and driers.

To thin it so it can be used, Toluene (RM-111), Toluene substitute (T-62), or a mixture of the two is used. Drying may be retarded and surface appearances improved by adding 15 to 25 percent thinner (T-25 or T-29). The amount of thinning depends on the method of application.

Three usual methods of applying primer are by BRUSH, SPRAY, and DIP. Ordinary shop application usually involves the brush method. Spraying, however, is the most satisfactory method of handling large quantities of material.

For spraying, the primer is reduced by the addition of two to two and one-half parts of thinner to one part of the primer. A thin, wet coat must be applied. Thin coats are applied by working the spray gun at a greater distance from the surface of the metal.

When applied by brush, the primer is thinned with one to one and one-half parts thinner to one part primer. The primer must be spread quickly and WITHOUT REWORKING the brush over the already coated areas. Good quality brushes should be used.

When you apply primer by dipping, use approximately one-half to one part thinner to one part primer. In practice, the dipped part should be withdrawn slowly enough to permit the excess zinc chromate primer to

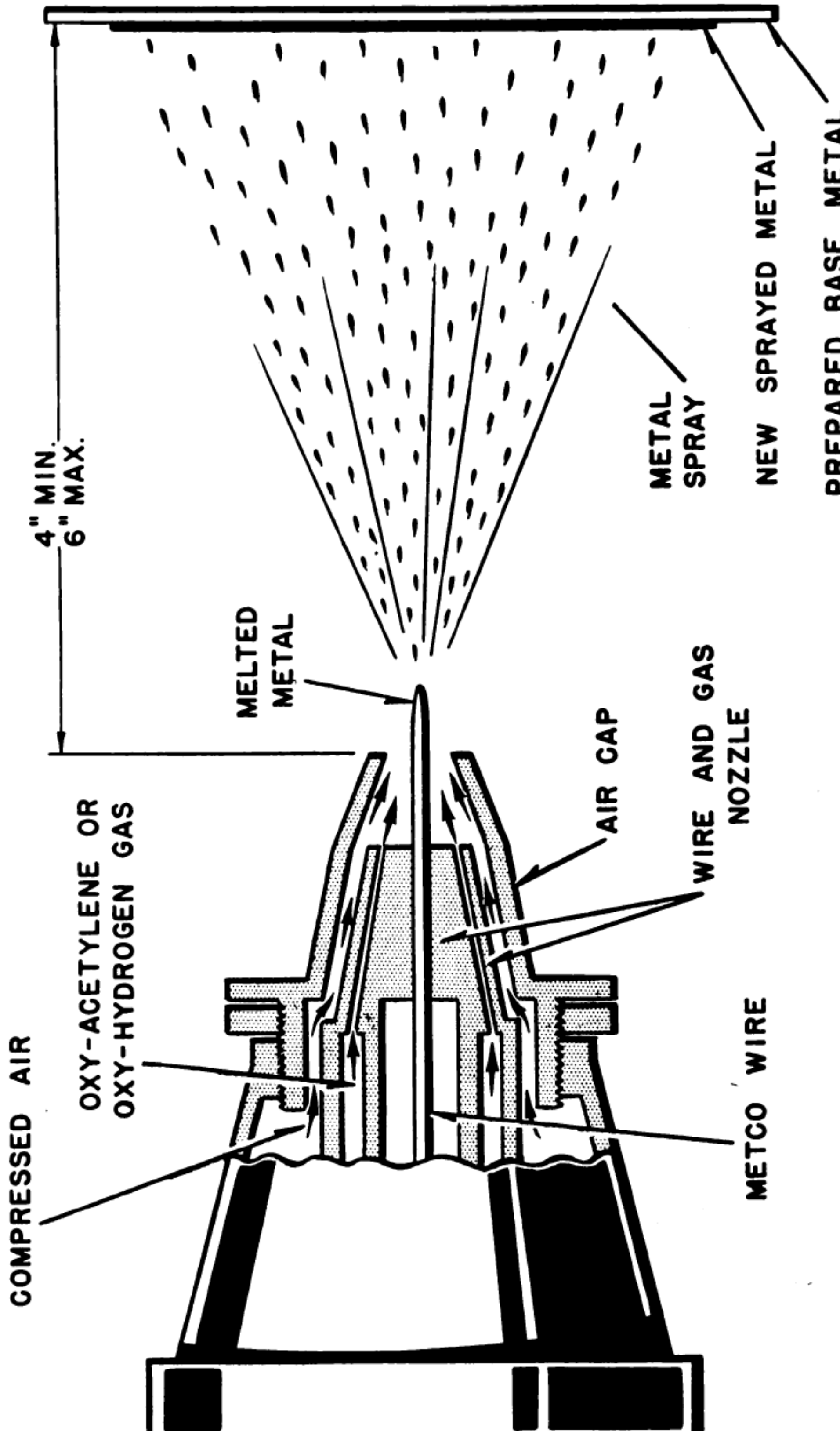


Figure 40.—Wire nozzle and air cap cross section.

run off before the wet area is more than a slight distance above the surface of the liquid.

Watch the color of your primer! Coated metal with a distinctly yellow-greenish cast is JUST RIGHT. But a metal with full yellow color shows a coating that is too heavy and a primer that should be thinned.

METALLIZING

Metallizing or metal spraying is the application of a molten coating of such metals as aluminum, cadmium, copper, nickel, and steel to the surface of another metal or any other solid material. In the aircraft industry it is used to prevent corrosion between dissimilar metals, to protect a surface, corrosion prevention, and to provide a better base for paints.

Your main working equipment is a METALLIZING GUN. It is operated by feeding the desired wire into the nozzle

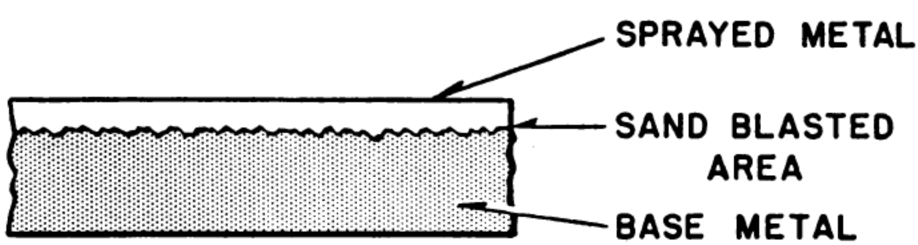


Figure 41.—Sandblasted and metallized surface.

of the gun so that it is melted by an oxyacetylene flame in front of the nozzle of the gun. A blast of compressed air drives the molten metal from the end of the nozzle to surface to be metallized.

Figure 41 shows how a bond is obtained between a sand or grit blasted surface and the sprayed coating.

After you've prepared and cleaned the base metal surface properly, spray the melted metal by holding the gun four to six inches from the work and at right angles to it. The gun is moved back and forth over the metallized area with about a 30 percent overlap

until the entire surface is evenly covered. Each layer should be applied at right angles to the previous one.

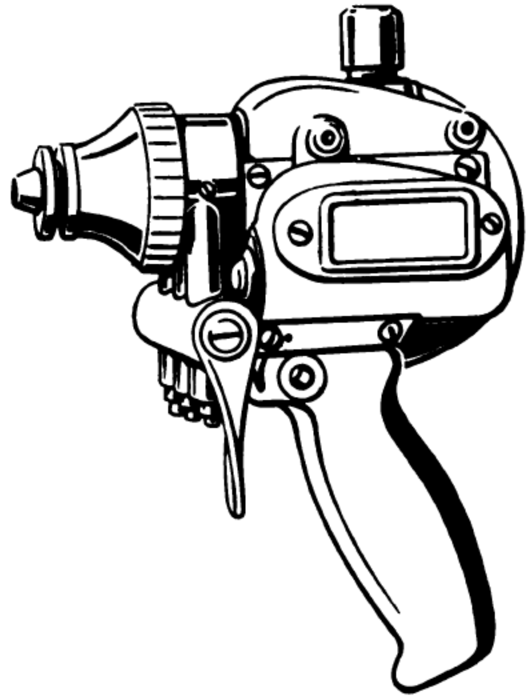


Figure 42.—Metallizing gun.

RUST PREVENTIVES

Long before zinc chromate primer and metallizing saw service as corrosion preventives, some form of grease or oil was applied to keep rust from attacking metal surfaces. These were referred to as RUST PREVENTIVE COMPOUNDS and included no-oxide grease, beeswax and grease, tallow and white lead, Ruse Veto and "Lionoil." All of them have been replaced by a compound known by the trade name of PARALKETONE.

Paralketone is intended for use as an all-purpose rust preventive for both ferrous and non-ferrous metals. It can be used as a corrosion preventive under the most severe conditions of exposure. Although it may be used directly on metal as an emergency measure, it should not be considered as a substitute for painting, anodizing, and other preventive measures.

Before Paralketone is applied, the surface of the metal must be free of all moisture, grease, dirt, and the like. There are two types of Paralketone. Type I is cold application material, and Type II is hot application material. Grade A is compound with a low melting point, and Grade B has a high melting point.

Type I is most commonly used because it can be used as a dip or spray, or it may be applied with a brush within the temperature range of 40° to 95° F. Type II has an application range from 150° to 220° F. It's used only as a dip.

Bolts, wires, fittings, and exposed ends of airfoil struts and cables are brushed or dipped. Open end struts on seaplanes, as well as welded parts of tubular structures, are flushed with Paralketone.

ANODIZING

As an Aviation Metalsmith you are especially concerned with the prevention of corrosion on aluminum and aluminum alloys. One of two reliable chemical processes used to form an oxide film on the surface of these metals is called anodizing.

Anodizing causes the formation of a thin film of ALUMINUM OXIDE on the surface of the metal by electrochemical means. This film helps to prevent corrosion and offers a good base for paint.

Equipment required for anodizing includes—

DIRECT CURRENT GENERATOR outfit with an output of 50 to 100 volts and up to 1,000 amperes.

CONTROL PANEL complete with voltmeter, ammeter, and overload circuit breakers.

STEEL ANODIZING TANK equipped with bus bars, steam heater, and ventilators.

STEEL RINSE TANK equipped with facilities for heating water to boiling point.

STEEL ANODIC STRIP tanks equipped with steam heating coils.

The solution used in anodizing consists of nine and

one-half to 10 percent chromic acid by weight, and water. The chromic acid is usually obtained in slate form in 100 pound metal containers.

When you work with chromic acid, PLAY IT SAFE! Remember that—

RUBBER GLOVES AND APRON should be worn. When chromic acid comes in contact with the skin it may cause "chrome sores" which are very difficult to heal.

Clothing worn while working with chromic acid should be KEPT CLEAN. Fumes of the acid will stay in clothing and possibly cause skin irritation.

Acid spilled on the clothing will eat up cloth in the same manner as battery acid.

FUMES OF CHROMIC ACID ARE TOXIC, so ample ventilation should be provided.

A part to be anodized is suspended from the ANODE BAR and is placed in the chromic acid solution, which is heated to 98° F. This bar is usually in the center of the tank and the positive lead is connected to it. The tank itself acts as the CATHODE or negative lead. The current is brought up fast to approximately 40 volts. Small parts generally will draw about 250 to 300 amperes. The part is anodized for a period of about 30 minutes, after which time the current is decreased rapidly. The part is then removed and rinsed in the hot water rinse tank with the rinse water heated to near the boiling point.

The treated metal will be gray in color and should be free from scratches or nicks. If the anodized surface is defective, you can remove it for re-anodizing by dipping in a hot STRIPPING SOLUTION of 20 percent caustic soda, two percent rosin, and water for 20 to 30 seconds. This will leave a dark film on the metal which may be removed by dipping into a 20 percent nitric acid and water bath. Such treatment will brighten the metal and also stop the action of the caustic soda strip. This should be followed by a thorough rinsing.

Aluminum alloys which contain more than five percent copper MUST NOT BE ANODIZED—the chromic acid

will attack the copper and destroy the strength of the alloy. NEITHER CAN MAGNESIUM ALLOYS BE TREATED IN THIS SOLUTION.

If a part contains non-removable inserts of steel and copper, brass bushings, and nuts or screws, STOP OFF these items with a suitable acid resisting substance or material before the part is anodized.

CHROMIC ACID TREATMENT

The other chemical process used to protect aluminum and its alloys is employed IN THE FIELD. You use it where anodizing equipment is not available.

The treatment consists of immersing the part in a five to 10 percent chromic acid solution heated to 120° to 140° F. for a period of five to 10 minutes. The solution should be agitated during the dipping—a good way being to send a flow of compressed air through perforated tubes placed in the solution.

Another method of giving surface treatment is known as the CHROMIC ACID STAIN. In this method you use a soft cloth or brush to apply the acid solution directly to the part to be treated. Care should be taken to prevent the solution from getting into the joints. Allow it to remain on the surface from five to 10 minutes. Then wash the part with hot water, scrubbing lightly with a bristle brush.

The "Alrok" process of the Aluminum Company of America is similar to the chromic dip, and the same firm's "Aluminite" process produces a heavy anodic film of aluminum oxide.

To beat corrosion, two aluminum manufacturers developed special alloys known by the trade names "Alclad" and "Pureclad."

Alclad designates an aluminum alloy which has a coating of pure aluminum approximately five percent the thickness of each surface. The coating is PRESSED on to the alloy base and gives it a good protective coating. An unusual feature of the Alclad coating is

that it not only protects the sheet it covers, but also, to a large extent, the cut edges and rivet heads. This is due to an electrolytic action set up between the pure aluminum and the alloyed metal. Pureclad is the same type material.

Alclad is marked by the abbreviation, "ALC," and Pureclad is indicated by the letters "PC." Handle Alclad and Pureclad CAREFULLY. Scratches on the surface leave the alloy unprotected.

PROTECTION FOR MAGNESIUM

Under ordinary land exposure conditions, magnesium and its alloys are strong in resisting corrosion, although they will gradually darken and tarnish. When exposed to salt spray and salt air, however, magnesium corrodes at a relatively rapid and uniform rate. The surface is roughened—even pitted under extreme conditions. Surface protection for magnesium is provided by various chemical treatments which definitely reduce corrosion and make an excellent base for paint and lacquer.

CHROME PICKLE or DICHROMATE DIP, the most common treatments, use a sodium dichromate and nitric acid solution. The coating is applied to most magnesium parts at their place of manufacture. A number of other chemical treatments, such as DICHROMATE, CHROME-SULPHATE, and SEALED CHROME PICKLE are used for securing special effects on the metal.

In areas where corrosion is common, chemical treatments for magnesium are supplemented by paint protection. For naval aircraft, magnesium parts should first be given a chemical treatment, then a primer coat, and finally a coat of varnish, lacquer or paint. Before ANY treatment is applied, of course, the surface should be free of all dust, dirt, oil, grease, oxides and the like.

PARKERIZING AND PASSIVATING

PARKERIZING is a process of coating ferrous metal by

placing it in a bath of dilute iron phosphate that has been heated to the boiling point. The metal must remain in the solution until the "gassing" ceases. Then it is removed and dipped in oil to give it a deep black color. The coating is a mixture of ferrous and ferric phosphate and black iron oxide and the process is exceptionally good for coating the inside of tubular members which cannot be electroplated.

YOU NEVER plate stainless or corrosion-resisting steels. You give them a treatment known as PASSIVATING.

Passivating consists of immersing the material for 20 minutes in a solution of 15 to 20 percent nitric acid, at a temperature of 120° to 150° F. After treating, be sure to rinse the metal thoroughly in warm water.

Passivating accomplishes two purposes—it removes any small particles of metals of dissimilar nature that may have adhered to the surface of the stainless steel from previous operations and it accelerates the formation of a tough, passive, oxide surface film. This treatment does not affect the appearance of the polished metal.

ELECTROPLATING

Electroplating, an electrical process carried out at a low voltage, deposits METAL directly on the surface of the part being plated. This process is used on a large number of steel, copper, and brass parts of an airplane. Parts such as bolts, nuts, washers, cotter pins, steel fittings, and others.

In general, electroplating is accomplished by passing a direct electric current through a solution between two metallic surfaces. One metal surface is dissolved and deposited on the other metal surface. You call the solution through which the current passes the ELECTROLYTE. In addition to water, it contains a compound of salt composed of the metal to be deposited, and other substances which improve the conductivity of the solution. The objects through which the current enters and leaves the solution are known as the ELECTRODES.

You call the electrode through which the current enters the solution, the ANODE, and the electrode through which the current leaves the solution and on which the metal is deposited, the CATHODE.

You consider several factors in deciding what kind of plating to use. You think in terms of resistance to corrosion and resistance to wear. You consider the color and luster, and the plating thickness desired.

In plating operations you use zinc, cadmium, nickel, chromium, copper, cobalt, iron, lead, tin, silver, gold, or platinum. Of these, the first four are the ones most frequently used for aircraft work.

Usually, you'll find that the same procedures are

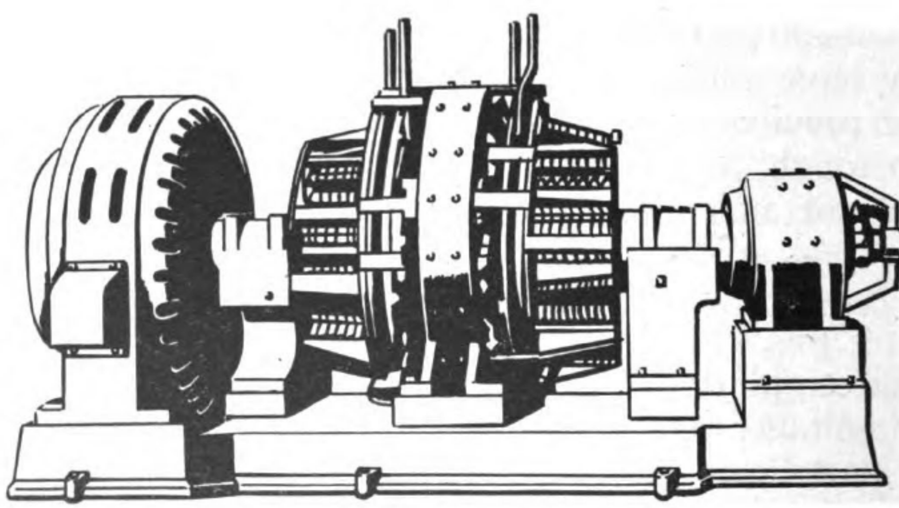


Figure 43.—Generator set.

followed with all these metals. But solutions, temperatures, and current densities CHANGE. Consult a platers' handbook to get specific information on them.

For any kind of plating you'll need electrical equipment. You'll need a motor generator set or a storage battery for small installations. And you'll need a suitable control panel, wiring, and controls to regulate the current and the tank.

You estimate the amperage output required for a job by multiplying the number of square feet of work

surface by the number of amperes per foot. Usually, 15 to 30 amperes per square foot is satisfactory.

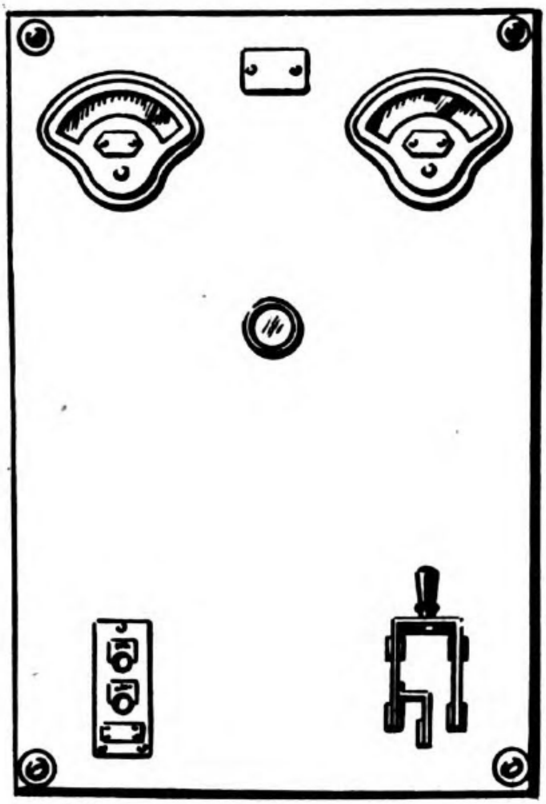


Figure 44.—Generator control panel.

For ordinary aircraft plating, a six to 12-volt generator with a 250 to 300 ampere capacity is adequate.

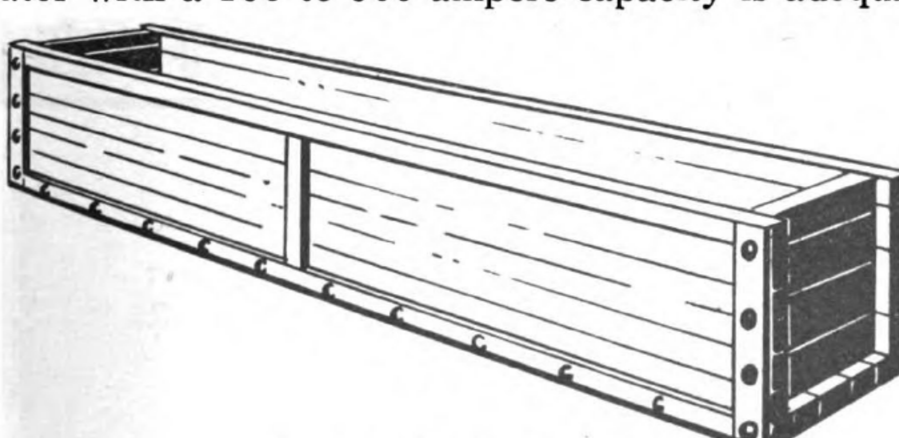


Figure 45.—Plating tank.

Plating and cleaning tanks are provided with suitable anode and cathode rods, wiring, and heater. They

are usually constructed of wood or steel. If they are made of wood, they should have a steel lining. You'll need a control panel for each tank requiring electricity. That's to control the density of current flowing through the tank.

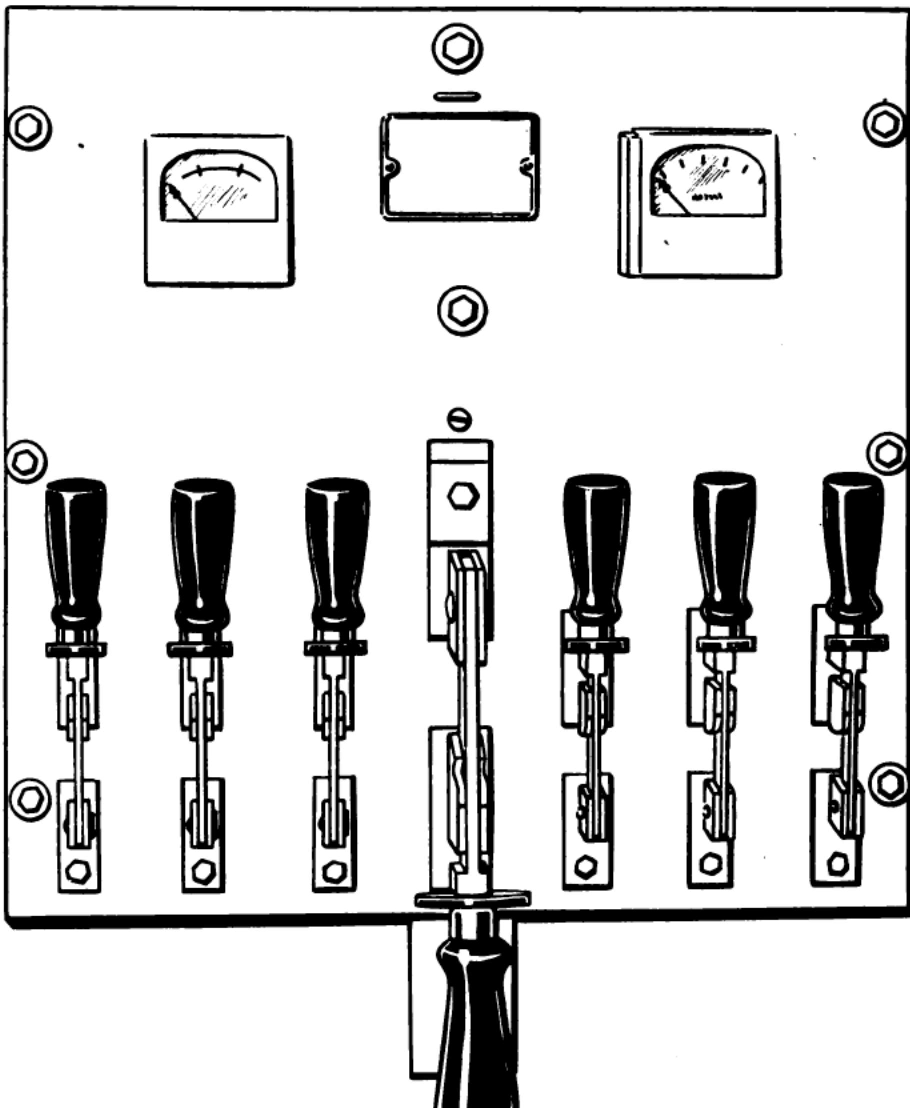


Figure 46.—Tank control panel.

You should have still plating, electro-cleaning, hot water rinse, cold water rinse, and pickling and bright dip tanks for plating. The last is lined with lead or stoneware.

Remember that you must clean metal thoroughly before plating is attempted. Otherwise the plate will not ADHERE to the base metal.

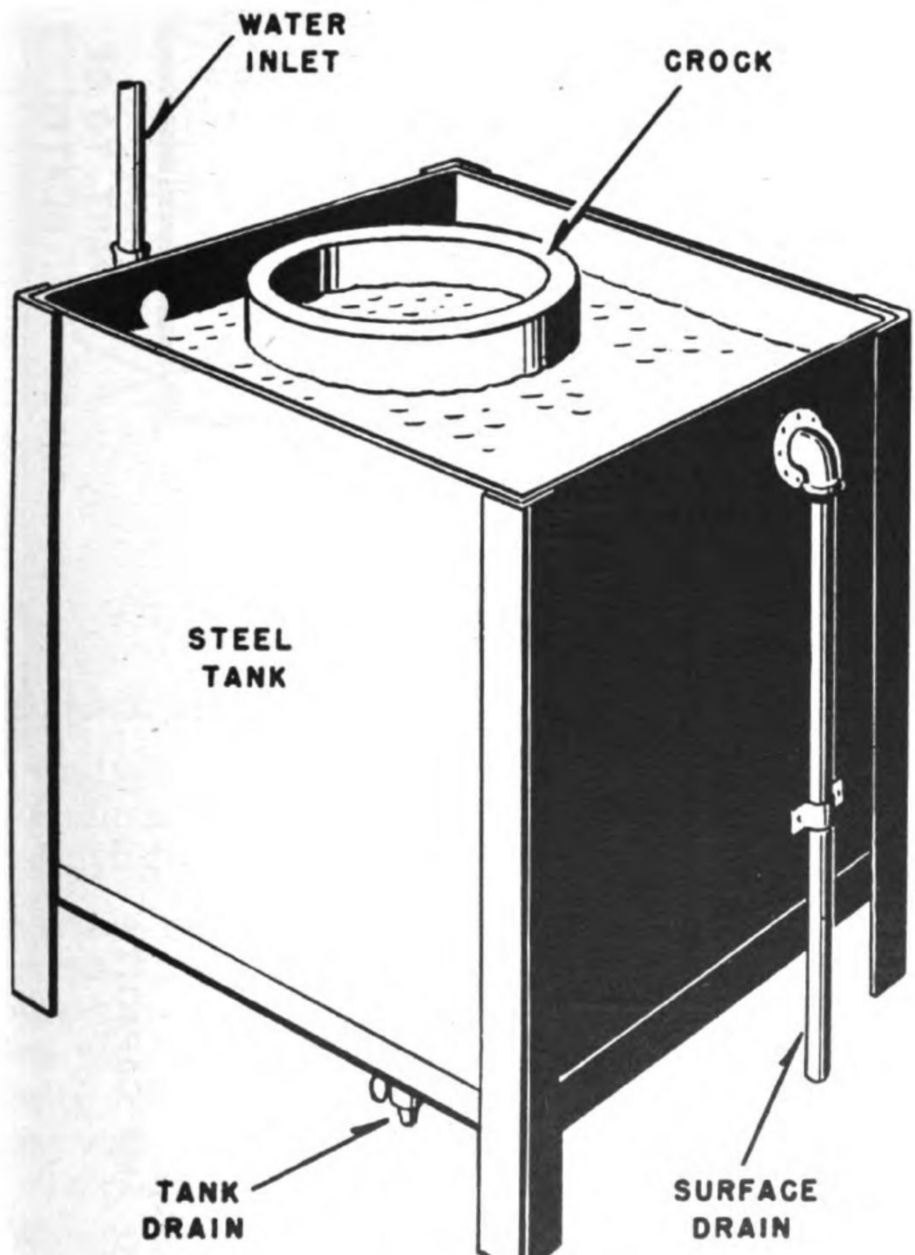


Figure 47.—Typical pickling tank.

Plating solutions are usually composed of a solution of SALTS OF THE METAL to be plated, a CONDUCTOR AGENT, and a BRIGHTENER. A typical solution for

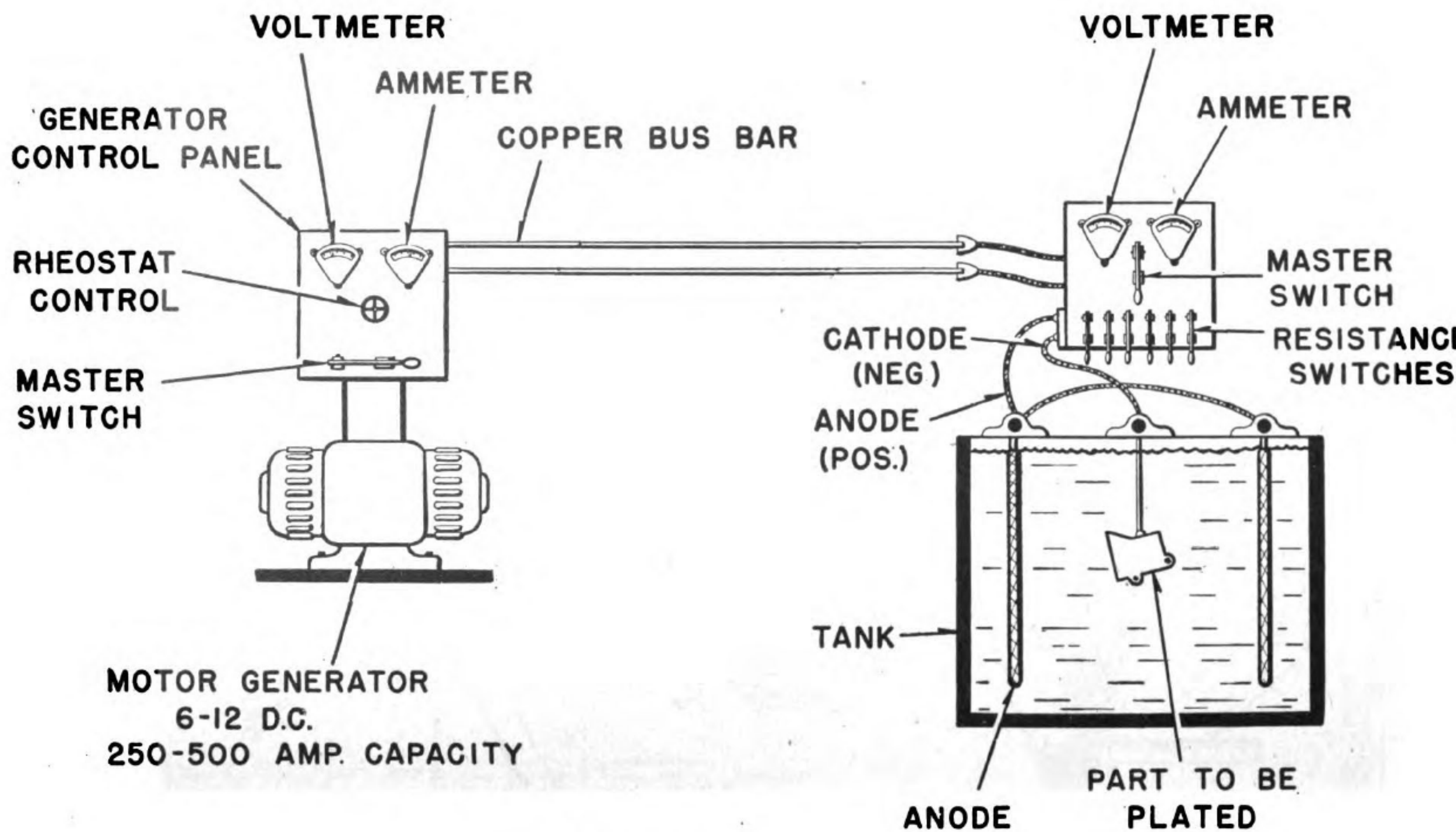


Figure 48.—Typical plating tank wiring diagram.

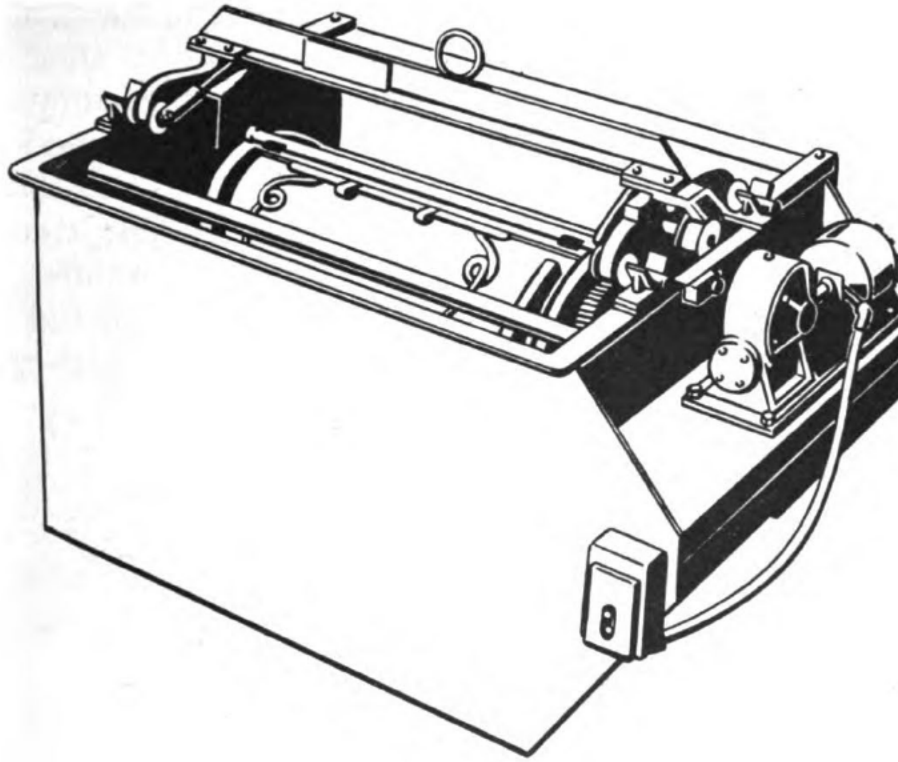


Figure 49.—A barrel plater.

cadmium plating, as an example, includes—

Cadmium oxide	3 oz. per gal.
Sodium cyanide	12.5 oz. per gal.
Udybrite salts (commercial)	4 lbs. per 100 gal.

When you mix acids, always ADD THE ACID TO THE WATER SLOWLY. NEVER add water to the acid, or the heat generated may cause an explosion. Then, too, you must provide ample ventilation because the majority of the chemicals used are somewhat toxic and may cause injury to a person's health.

To plate a part which has been thoroughly cleaned, place it in the solution and suspend it from the cathode bar. The electrical operating current is set for the size of the part being plated. The amount of time and current depends on the quantity of work and the thickness of deposit you want.

If a number of small parts are to be plated, a barrel plater may be used.

Plating solutions should be maintained in the proper proportions to give best results. The most effective way to do this is to get test kits from the company which supplies the solution and follow its instructions for testing. That holds, also, for testing for the thickness of the deposit of the plated material. Most companies have these kits made up for the particular type of test you want to make. They usually include a mixture of chemicals and graduated beakers with specific instructions on conducting tests.

PAINTING

Any paint used in aircraft work must be resistant to corrosion, have good adhering qualities, and be elastic in order to prevent cracking.

The location of the parts to be painted usually governs the type of paint to be used. For example, battery boxes are painted with acid resistant paint, and bituminous paint is used on the interior of floats and hulls.

Most paints are composed of PIGMENTS and VEHICLES. Pigment gives color, solidity, and hardness to the paint. Vehicles are liquids and are used to cement the pigment together and strengthen it after drying. Vehicles are generally divided into two classes. The first class includes the SOLIDIFYING OILS such as tung oil or China wood oil, and linseed oil. These oils, when dried, become tough, resilient, and free from cracks. The second class, VOLATILE OILS such as turpentine, benzine, toluene, and alcohol, are used to dilute the paint and to dissolve varnish resins. These "spirits," as they are commonly called, evaporate when exposed to the air.

Lacquers and varnishes are different from paint. They are composed of pigments, resins, and volatile oils. Lacquers are noted for their rapid-drying qualities.

The job you have at hand more often than not will determine the selection, preparation, and application of paints, lacquers, and varnishes. Consult your Navy specifications for detailed information.

CHAPTER 7

PHYSICAL TESTING OF AIRCRAFT METALS

THE BEST IS YET TO COME

ALL MATERIALS USED IN AIRCRAFT CONSTRUCTION MUST MEET CERTAIN STANDARD INSPECTIONS AND TESTS.

If a manufacturer knows the properties of his metals and alloys, he can determine whether or not they are suitable for certain purposes, and he can modify their heat treatment and mechanical working, so as to get them into the most desirable form. Generally speaking, testing methods enable us to predict pretty confidently—from tests run on a small piece of material—how a large specimen of that same material will behave in actual service.

Frequently, attempts to fool-proof one part of a plane will lead to an entirely new technique in designing and fabricating other parts. When one of our large aircraft plants was working on the problem of propeller-tip breakage, testing engineers designed a new set-up to study the effect of vibration on propellers.

As matters then stood, the propellers had to be decidedly overweight, or the fatigue of the metal caused them to break. The engineers got going—and things started happening. When the test was finished, they emerged with a much improved propeller design, not to mention improvements in the engine and other parts of the plane. The new propellers were 200 pounds lighter than the old ones, thus saving from 200 to 800 pounds per airplane. These planes fly higher and faster now. Company engineers know their propellers better, too, and can forecast accurately how they will behave in service.

Don't think this is an isolated case, either. Testing engineers are pulling new rabbits out of their hats every day. At least two of our large aircraft companies built million-dollar testing laboratories—and in the entrance of one hangs the slogan, "The Best Is Yet To Come."

The primary problem in all such workshops is to determine the physical properties of various materials, their adaptability to aircraft, their availability and price, and the UNIFORMITY OF THEIR PROPERTIES. (See tables XIII and XIV.)

The experts write their own answers. They have their own fabricating shop, which produces the necessary testing equipment and such specimens as they cannot buy. The test block for landing gear is designed to meet any loading conditions, and extremely heavy landings. Here you will find devices to test the biggest landing gears on the market. Castings get the works. Bent aircraft parts are vibrated to determine the breaking point. Scientists check steel tapes for vibration data recorded during test flights.

There are problems in forming certain metals, problems of executing new designs, problems in corrosion treatment, problems in welding, and problems in pressurizing airplane cabins for high-altitude flying.

This last teaser is only one small part of that particular puzzle. Most of its pieces are put together in

the "Stratosphere Chamber," where aircraft metals and the working parts of a plane are tested for low-temperature flying. The cold chamber was first enlisted for aviation research about 1920, and its use as a testing medium has steadily increased in importance since that time. The "chill chamber" at the Naval Aircraft Factory in Philadelphia will accommodate a large fuselage without wings or an entire small plane without wings.

Testing engineers crowd into the larger cold chambers, armed with all sorts of data on aircraft metals and alloys and intent on such weighty problems as THE

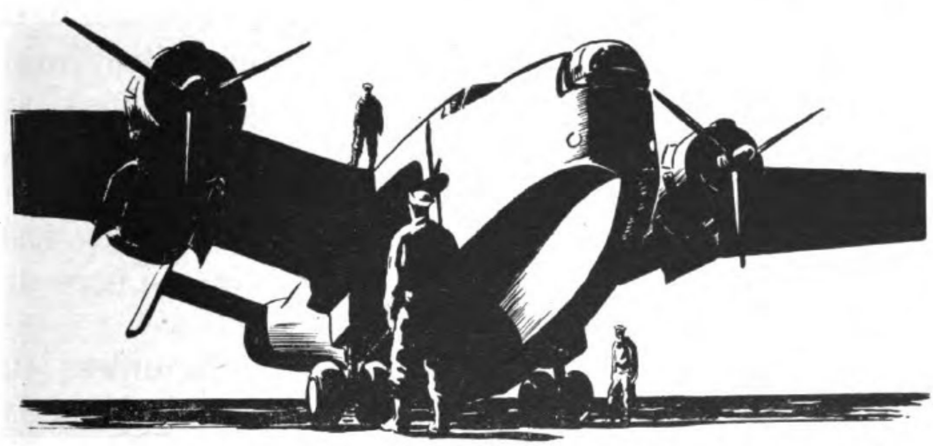


Figure 50.—Navy airplanes win their wings in test tubes.

UNEQUAL CONTRACTION OF UNLIKE MATERIALS THAT IS CAUSED BY RADICAL CHANGES IN TEMPERATURE. Their enthusiasm may wane after four or five hours at 40° F., but airplanes fly higher and more safely because of their work.

Buck Rogers would feel right at home among the wonder-working gadgets in these up-to-the-minute testing laboratories. There's a delicate instrument that traces vibrations through sound recordings—a huge mock-up of a 4-motored plane—photomicroscopes that magnify pictures of tiny welds and make flaw-finding easier—and machines that work metal through thousands of vibrations a minute, hour after hour and day

after day. A salt spray test shows in a few days what normal corrosion would take years to produce. There's a huge form that sizes up the amount of stress a wing spar can stand, a floor that can take stationary test loads as heavy as they come and a pressure of 400,000 pounds anywhere on its surface. A giant vibrator shakes wings to pieces, and AN ELECTRON MICROSCOPE MAGNIFIES EVEN THE TINIEST SPECK A BILLION TIMES. The X-ray apparatus is something out of this world, too.

INSPECTION COMES FIRST

To determine accurately the properties of any material, you've first got to run a series of related tests on it. Some properties can be determined by simply looking at your metal carefully. For others, you will need the aid of instruments. (This gives you "VISUAL INSPECTION, EITHER WITH OR WITHOUT THE AID OF INSTRUMENTS.") You will have to use laboratory testing machines to determine some properties. There are others that will require chemical analysis.

Your findings will be worthless, though, unless the results of each and every one are interpreted correctly. And that takes both intelligence and experience.

The metals used in aircraft construction are tested probably more rigorously than those used in any other industry. Airplane designers try to get the last ounce of strength out of each part. And this would be a risky business indeed, if the exact strength of the basic materials were not known. So they set about discovering the strength by a series of tests. And those tests are TOUGH! What that metal goes through before it hits the air makes boot camp look like fun.

The TENSION TEST is probably the best of the lot, when it comes to determining the basic properties of a metal. You can get from it the ultimate tensile strength, yield strength, elongation and reduction of area. Yield strength indicates the maximum applied load that the metal can withstand, and elongation and

reduction of area are a measure of its ductility and ease of working.

Most specifications for aircraft metals require a BENDING TEST. This test gives positive proof that a metal is ductile and not inclined to brittleness. The bending may be done either by constant pressure or by hammers, but hammers are used for this work in most aircraft shops. Specifications that insist upon the bending test usually require that specimens be taken both parallel to and across the grain of the metal. Fortunately, the high-grade aircraft metals now available can be bent in any direction without cracking and still pass all tests with flying colors.

Round steel wire usually has to pass a reverse bend test, that is, be bent back and forth. Requirements vary from 50 bends for small wire to 7 bends for heavy wire. And there is a bending test that can be used for aircraft tubing.

Aircraft tubing is practically always put through a FLATTENING TEST in which it is compressed endwise under a gradually applied load and must take plenty WITHOUT CRACKING.

Welded tubing or seamless tubing that will carry pressure when in service, such as the corrosion-resistant steel tubing used for exhaust collectors, is given a HYDROSTATIC PRESSURE TEST. Welded exhaust tubing is put under enough internal pressure to subject the welded seams to a tensile strength of 10,000 psi. This test is a necessity because aircraft tubing must often bear up under high internal pressure. The oxygen in aircraft oxygen apparatus, for instance, is carried under an 1,800 psi pressure through a three-sixteenth-inch copper tube that conveys it from storage tank to regulator.

Because of the extensive use of metals and alloys as electrical conductors and heating elements, their electrical resistance must be determined. Such tests are done most easily on wire.

Wire is subjected to a torsion test as well. Metals

that will be subjected to vibration get fatigue testing. Aircraft cable is tested in machines that, running day and night, duplicate the fatigue conditions the cable must meet in flight and measure the number of bending stresses it can stand under load.

Forgings, such as those used in steel propeller blades, must stand up under macro-etch tests, shear inspection, magnaflux examination, and microscopic determination of the number and type of any non-metallic inclusions that may occur in the metal. The standards of acceptance and thoroughness of inspection for aircraft forgings go beyond those usually applied to high-grade alloy steels destined for other uses. Many of the tests are applied to each and every forging. Sometimes, macro-etch tests are made at the forging machines to find out if the metal is porous or suffers from segregation. Often, in the case of such important parts as propeller hubs and blades, a tensile test piece is pulled from the "coupon" attached to each forging and tests are run on the various specimens simultaneously.

Both the Navy and Army make use of the laboratory and research facilities of the National Advisory Committee for Aeronautics at Langley Field, Va. Here you will find magnaflux testing equipment, propeller balancing apparatus, and the world's largest tank for testing hulls and floats. Propeller blades are inspected regularly for cracks. Models and airfoils are "flown" in the 500-mph blast of the enormous NACA wind tunnel, which duplicates flying conditions insofar as possible.

Here, two giant 4-bladed propellers, each more than 35 feet in diameter and driven by 24,000-hp electric motors, direct a 120-mph gale over airplanes that are undergoing test. There are 18 other wind tunnels at Langley, with air speeds up to 760 mph, and the tests run in them sometimes add as much as 50 mph to the top speed of an airplane.

NACA hasn't put all its eggs in the Langley Field basket, however—its research and testing equipment

are centered at two other strategic locations, Moffatt Field in California and Cleveland, Ohio.

The Cleveland laboratory has more than 20 major buildings on its 200 acres of land and employs nearly 3,000 persons. Its big wind tunnel, which takes FULL-SIZED airplanes and where air flows at more than 500 miles an hour, is the only place on earth where per-

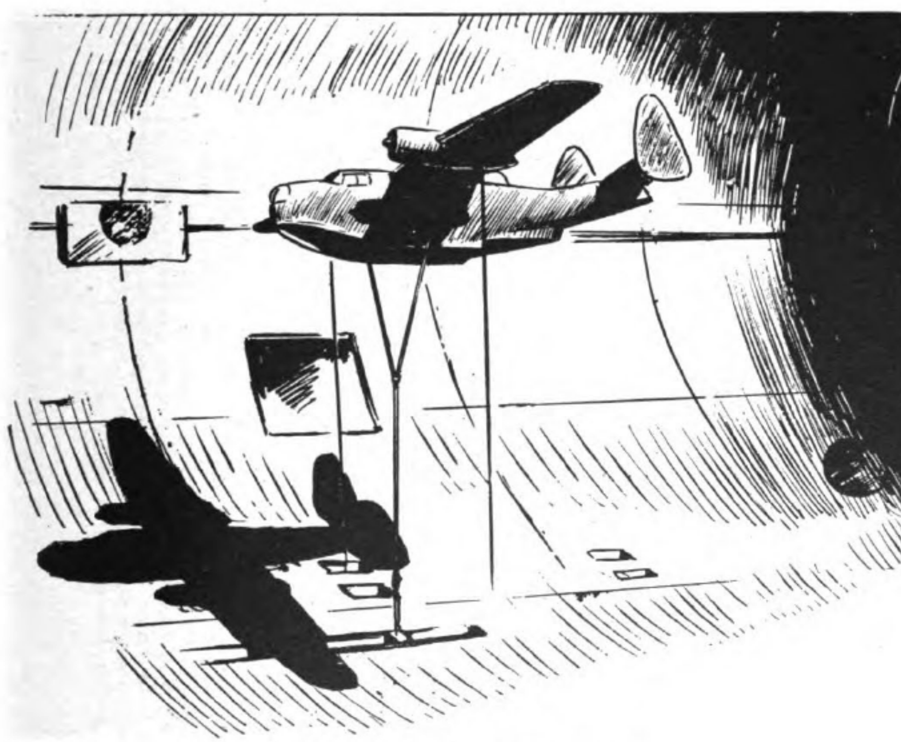


Figure 51.—Wind tunnel.

formance of jet engines can be investigated under altitude conditions. Temperatures of 60° below zero and altitude conditions over 50,000 feet can be duplicated.

Under recent appropriations made for the Cleveland laboratory, it is expected that new supersonic wind tunnels having air speeds much faster than the speed of sound, and ranging up to 2,000 miles an hour, will be built.

SOME PRACTICAL CONSIDERATIONS

In your own testing problems, there are two proper-

TABLE XIII

IDENTIFICATION OF METALS

		WHITE CAST IRON	GRAY CAST IRON	MALLEABLE IRON*	WROUGHT IRON	LOW-CARBON STEEL AND CAST STEEL	HIGH-CARBON STEEL
APPEARANCE	FRACTURE.	Very fine silvery white silky crystalline formation.	Dark gray.	Dark gray.	Bright gray.	Bright gray.	Very light gray.
	UNFINISHED SURFACE.	Evidence of sand mold; dull gray.	Evidence of sand mold; very dull gray.	Evidence of sand mold; dull gray.	Light gray smooth.	Dark gray; forging marks may be noticeable; cast—evidences of mold.	Dark gray; rolling or forging lines may be noticeable.
	NEWLY MACHINED SURFACE.	Rarely machined.	Fairly smooth; light gray.	Smooth surface; light gray.	Very smooth surface; light gray.	Very smooth; bright gray.	Very smooth; bright gray.
CHIP TEST	APPEARANCE OF CHIP.	Small broken fragments.	Small partially broken chips but possible to chip a fairly smooth groove.	Chips do not break short as in cast iron.	Smooth edges where cut.	Smooth edges where cut.	Fine grain fracture; edges lighter in color than low-carbon steel.
	SIZE OF CHIP.		$\frac{1}{8}$ in.	$\frac{1}{4}$–$\frac{3}{8}$ in.	Can be continuous if desired.	Can be continuous if desired.	Can be continuous if desired.
	FACILITY OF CHIPPING.	Brittleness prevents chipping a path with smooth sides.	Not easy to chip because chips break off from base metal.	Very tough therefore harder to chip than cast iron.	Soft and easily cut or chipped.	Easily cut or chipped.	Metal is usually very hard but can be chipped.

SPARK TEST	COLOR, SHAPE, AVERAGE LENGTH WITH POWER GRINDER, AND ACTIVITY OF SPARKS ARE DISTINGUISHING DETAILS.	—Color—red to straw yellow. —Average length with power grinder—20 in. —Volume very small. —Fewer sparklers than gray cast iron. —Sparklers are small and repeating.	—Color—red to straw yellow. —Average length with power grinder—25 in. —Volume small. —Many sparklers. —Sparklers are small and repeating.	—Color—straw yellow. —Average length with power grinder—30 in. —Volume—moderate. —Many sparklers. —Sparklers are small and repeating.	—Color—straw yellow to white. —Average length with power grinder—65 in. —Volume large. —Very few sparklers. —Sparklers are forked.	—Color—white. —Average length with power grinder—70 in. —Volume moderately large. —Few sparklers. —Sparklers are forked.	—Color—white. —Average length with power grinder—55 in. —Volume large. —Very many sparklers. —Sparklers are small and repeating.
BLOW-PIPE TEST	SPEED OF MELTING. (From Cold State).	Moderate.	Moderate.	Moderate.	Fast.	Fast.	Fast.
	COLOR CHANGE WHILE HEATING.	Becomes dull red before melting.	Becomes dull red before melting.	Becomes red before melting.	Becomes bright red before melting.	Becomes bright red before melting.	Becomes bright red before melting.
	APPEARANCE OF SLAG.	A medium film develops.	A thick film develops.	A medium film develops.	Oily or greasy appearance with white lines.	Similar to molten metal.	Similar to molten metal.
	ACTION OF SLAG.	Quiet; tough, but can be broken up.	Quiet; tough, but possible to break it up.	Quiet; tough, but can be broken.	Quiet; easily.	Quiet.	Quiet.
	APPEARANCE OF MOLTEN PUDDLE.	Fluid and watery; reddish white.	Fluid and watery; reddish white.	Fluid and watery; straw color.	Liquid; straw color.	Liquid; straw color.	Lighter than low-carbon steel has a cellular appearance.
	ACTION OF MOLTEN PUDDLE UNDER BLOWPIPE FLAME.	Quiet; no sparks; depression under flame disappears when flame is removed	Quiet; no sparks; depression under flame disappears when flame is removed.	Boils and leaves blowholes; surface metal sparks; interior does not.	Does not get viscous; generally quiet; may be slight tendency to spark.	Molten metal sparks.	Sparks more freely than low-carbon steel.

°Very seldom used commercially. *Malleable iron should always be bronze-welded.

Reproduced from the Oxwelders Handbook by permission Linde Air Products Co.

ties of aircraft parts and structures that needn't bother you—their weight and size. The weight is extremely important, but it can be determined without much difficulty. Dimensions, size, and similar qualities of finished aircraft parts vary in importance, according to the use for which the parts are designed. Measurements often increase in difficulty as parts increase in importance.

Thus, while it's okay to measure some parts with an ordinary ruler or scale, the greater percentage require more accurate measurement, for they must comply with the most exacting standards of precision. This means elaborate and extensive measuring equipment and a competent staff to use it. So, while weight and dimensional accuracy are important, this chapter will not cover the methods used in checking them. It will be concerned instead with some of the methods used to determine other properties which you, as an Aviation Metalsmith, should know—properties that are not usually as evident as size and weight.

Obviously, only general defects and characteristics may be seen in visual inspection without the aid of instruments. Experience comes in handy here, as you must know what defects to look for and how serious they are, once you've found them.

Generally speaking, you can tell the finish and workmanship of metal parts and materials by ordinary visual inspection and can see defects such as cracks, blowholes, rust, corrosion, and slag inclusions.

You may find that the most practical method of determining the physical characteristics of a metal is to be sure what metal you're working with, and then to check its characteristics with those set forth in Navy Department Specifications. You know, from what you've already learned about testing of aircraft metals, that the manufacturers aren't overlooking any bets along that line and that your metals will have uniform properties. So all you need do is to check them with the book.

In addition to this, four simple tests have been devised for your use in determining the kind of metal you are working with. These tests are known as—

APPEARANCE—The color, surface, characteristics, and appearance of the metal, when fractured, tell the story here.

CHIP TEST—Notice how easy (or hard) it is to chip the metal, and the characteristics of the chips formed when you make a narrow groove in it with a cold chisel and hammer.

SPARK TEST—Watch the color, shape, length, and activity of the sparks produced by holding the metal against a grinding wheel. The "activity" of sparks includes their volume and the type of sparklers.

OXY-ACETYLENE TORCH TEST—Observe the behavior of metal when it is melted with a welding torch. (Sometimes called the "blowpipe test.")

Tables XIII and XIV give the dope on these tests for some of the commonly used metals. It will help you to identify them and their various properties.

VISUAL INSPECTION VIA INSTRUMENTS

Suppose you need something more than your 20/20 eyes to inspect aircraft metals. What will you use? Three relatively quick and accurate methods offer themselves—X-RAY, MAGNETIC, and MICROSCOPIC INSPECTION.

There is much to be said in favor of X-RAY INSPECTION OF METALS AND METAL PARTS. Briefly, the X-ray process is nondestructive and can be used on finished parts as well as on the individual metals. X-rays are similar in many ways to ordinary light rays, although of much shorter wave length. However, they will pass through certain substances, such as metals, which ordinary light cannot penetrate. This quality makes them invaluable in searching for internal defects and X-ray inspection of castings, forgings, metals, and metal products has been standard factory procedure for some

TABLE XIV

IDENTIFICATION OF METALS

		ALLOY** STEEL	COPPER	BRASS AND BRONZE	ALUMINUM AND ALLOYS†	MONEL METAL	NICKEL	LEAD††
APPEARANCE	FRACTURE.	Medium gray.	Red color.	Red to yellow.	White	Light gray	Almost white.	White; crystalline.
	UNFINISHED SURFACE.	Dark gray; relatively rough; rolling or forging lines may be noticeable.	Various degrees of reddish brown to green due to oxides; smooth.	Various shades of green, brown, or yellow due to oxides; smooth.	Evidences of mold or rolls; very light gray.	Smooth; dark gray.	Smooth; dark gray.	Smooth; velvety; white to gray.
	NEWLY MACHINED SURFACE.	Very smooth; bright gray.	Bright copper red color dulls with time.	Red through to whitish yellow; very smooth.	Smooth; very white.	Very smooth; light gray.	Very smooth; white.	Very smooth; white.
CHIP TEST	APPEARANCE OF CHIP.	**	Smooth chips; saw edges where cut.	Smooth chips; saw edges where cut.	Smooth chips; saw edges where cut.	Smooth edges.	Smooth edges.	Any shaped chip can be secured because of softness.
	SIZE OF CHIP..	**	Can be continuous if desired.	Can be continuous if desired.	Can be continuous if desired.	Can be continuous if desired.	Can be continuous if desired.	Can be continuous if desired.
	FACILITY OF CHIPPING.	**	Very easily cut.	Easily cut; more brittle than copper.	Very easily cut.	Chips easily.	Chips easily.	Chips so easily it can be cut with penknife.
	COLOR, SHAPE, AVERAGE LENGTH WITH POWER GRINDER,	Color—straw yellow to white. —Average length with	No spark.	No spark.	No spark.	Spark very similar to nickel.	Color—orange. —Average length with power grind-	No spark.

SPARK TEST	AND ACTIVITY OF SPARKS ARE DISTINGUISHING DETAILS.	power grinder 50 in. —Volume—moderate. —Moderate number of sparklers. —Sparklers are forked.					er 10 in. —Volume—very small; wavy streaks. —No sparklers.	
	SPEED OF MELTING (from Cold State).	**	Slow.	Moderate to fast.	Faster than steel.	Slower than steel.	Slower than steel.	Very fast.
	COLOR CHANGE WHILE HEATING.	**	May turn black and then red; copper color may become more intense.	Becomes noticeably red before melting.	No apparent change in color.	Becomes red before melting.	Becomes red before melting.	No apparent change.
	APPEARANCE OF SLAG.	**	So little slag that it is hardly noticeable.	Various quantities of white fumes though bronze may not have any.	Stiff black scum.	Gray scum; considerable amounts.	Gray scum; less slag than Monel metal.	Dull gray coating.
BLOW-PIPE TEST.	ACTION OF SLAG.	**	Quiet.	Appears as fumes.	Quiet.	Quiet; hard to break.	Quiet; hard to break.	Quiet.
	APPEARANCE OF MOLTEN PUDDLE.	**	Has mirror-like surface directly under flame.	Liquid.	Same color as unheated metal; very fluid under slag.	Fluid under slag.	Fluid under slag film.	White and fluid under slag.
	ACTION OF MOLTEN PUDDLE UNDER BLOW-PIPE FLAME.	**	Tendency to bubble; puddle solidifies slowly and may sink slightly.	Like drops of water; with oxidizing flame will bubble.	Quiet.	Quiet.	Quiet.	Quiet; may boil if too hot.

** Alloy steels vary so much in composition and consequently in results of tests that experience is the best solution to identification problems. Stainless steel spark test is shown.

† Due to white or light color and extremely light weight aluminum is usually easily distinguishable from all other metals; aluminum alloys are usually harder and slightly darker in color than pure aluminum.

†† Weight, softness, and great ductility are distinguishing characteristics of lead.

Reproduced from the Oxwelders Handbook by permission Linde Air Products Co.

time. The use of this method in the detection of flaws, sand holes, and casting faults has prevented numerous accidents and saved many lives.

Perfect metal allows penetration of X-rays whereas imperfect metal, by blocking them, outlines the defects. It is thus possible to locate such flaws as sand inclusions, internal cracks, blowholes, pipes, segregation of the metal, gas cavities, porous sections, misalinement of parts, and lack of fusion between the welded and base metals in welded parts.

The foregoing results are commonly obtained by RADIOGRAPHY, or X-ray photography. This is one of the two principal industrial uses of X-ray, the other being the X-RAY DIFFRACTION PROCESS. Radiography is based on the passing of X-ray beams through an object and the obtaining of shadow pictures. Diffraction methods are based on the crystalline structure of metals and its arrangement for reflection of the X-ray beams. (The X-ray picture shows the position of the crystals within the structure itself.)

The most important use of this method is to get a working knowledge of original fiber structure and the distortion of fiber arrangement caused by heat treatment, forming, and cold-working. Armed with this data, you can forecast probable stress and fatigue failures.

THE NAVY DEPARTMENT REQUIRES—

1. Examination for stress.
2. Examination for grain direction and fiber structure.

X-ray examination was available originally only at factories and overhaul bases because X-ray equipment was too bulky to be carried about. But a portable X-ray unit, developed in 1942, is speeding up maintenance and servicing of aircraft in the field. This trailer-mounted X-ray lab is in service at most air stations and enables ground crews to make a complete diagnosis of possible danger zones within a few minutes after an airplane has landed. It reveals any structural damage

or metallic weakening, invisible to the naked eye, and indicates whether the plane shall be grounded for repairs or shall continue in action.

The trailer rolls up to a plane on the field and does its stuff. A yoke and boom arrangement makes it possible to reach every part of an airplane without dismantling it. An X-ray exposure is made and hustled into the portable dark room and waiting tanks of prepared developers at the rear of the trailer. The plate is developed in 15 minutes. The X-ray machine meanwhile has turned itself off like an automatic toaster.

MAGNETIC INSPECTION

The MAGNETIC INSPECTION PROCESS is used to DETECT CRACKS in steel bars, tubing, castings, welded joints, fittings, engine parts, propeller hubs and blades, and, generally speaking, any parts composed of material that can be penetrated magnetically. This quality is a "must," as THE PROCESS WON'T WORK UNLESS THE PARTS CAN BE MAGNETIZED. Metals that have low magnetic qualities—such as aluminum and its alloys, copper, bronze, and certain corrosion-resisting steels—cannot be checked by this method.

Magnetic inspection is also known as MAGNETOGRAPHIC INSPECTION OR MAGNAFLUX PROCESS. Magnaflux, as it is called commercially, is a standard inspection step in engine maintenance, and forgings are generally magnafluxed at various stages while being machined.

The part to be inspected is first magnetized, to create magnetic poles in any hidden cracks inside. The metal is then dipped in a solution of powdered iron and kerosene. The iron particles are attracted by the various magnetic poles that are formed along the edges of the cracks and break the bad news by clinging to the outside surface of the metal along the line of the hidden crevices.

It is often necessary to magnetize a part in more than one direction in order to check it completely, as

the magnetic poles will not form unless the cracks in the metal are approximately at right angles to the established lines of magnetic force. A good strong magnifying glass will help you to track down the hidden cracks.

If the iron particles don't seem inclined to congregate anywhere, you can give the metal a clean bill of health and send it on its way. MAKE SURE, though, that it is DEMAGNETIZED before it is placed in service.

Magnafluxing is like flying—you have to do plenty of it before you can be much good at it. The equipment is a push-over. Telling whether a crack is the real thing or a phony is what takes practice.

There are TWO WAYS TO MAGNETIZE METAL—the BIPOLAR METHOD and the CIRCULAR MAGNETIC FIELD

Figure 52.—Magnaflux testing of propeller parts.

METHOD. In the first, a direct current (high amperage and low voltage) is passed through the metal long enough to magnetize it. In the second, a magnetic field is established around and through the metal, and this

field is maintained throughout the test. The bipolar method has the edge on the other one as it requires only a comparatively small amount of equipment.

Consult Naval Aircraft Factory specifications for more information on the magnetic inspection process.

THE MICROSCOPE

The third aid to eyesight in the aircraft metals game is the microscope. It comes in handy in detecting small surface cracks and other similar flaws, but is most useful in studying such factors as the composition, grain, size, and structural arrangement of metals. The microscope is "in a class by itself" and you'll hear more of it later.

WANT TO TRY YOUR HAND AT TESTING?

THERE IS NO SHARP DIVIDING LINE BETWEEN INSPECTION AND TESTING of metals or any other materials. Their objective is the same—TO DETERMINE WHETHER MATERIALS ARE SUITED TO THE USES FOR WHICH THEY ARE DESIGNED. This covers a lot of territory, however, and it is more convenient to group some of the necessary procedures under inspection and others under testing. In general, TESTING INCLUDES THE METHODS USED TO DETERMINE THE PHYSICAL PROPERTIES OF A MATERIAL, such as hardness, ductility, elasticity, and tensile, compressive, and shearing strengths.

HARDNESS is the ability of a material to resist penetration. It is a relative quality, as all metals possess some degree of hardness. There are various kinds of hardness, depending on the form of stress imposed on the metal. Thus, there is tensile hardness, cutting hardness, abrasion hardness (resistance to wearing away by friction), and elastic hardness. MINERALOGICAL HARDNESS, the resistance offered by a smooth surface to abrasion, is particularly important in aircraft engine parts.

And there's DYNAMIC HARDNESS. Nobody knows too much about it, but it is certain that conditions of hardness are considerably moderated when the penetrating body is moving. Dynamic hardness sets up such opposition as resistance to the action of running water, the effects of a sandblast, and the pounding of dynamic loads on aircraft engine parts.

One of the earliest attempts at classifying materials according to hardness was the scale developed about the year 1800 by an ambitious gentleman named Friedrich Mohs. It was based on the ability of a harder mineral to scratch the surface of a softer one, and ranged from very soft talc, with a hardness of 1, to diamonds, with a hardness of 10.

It works like this. A substance with a hardness of 7½ would be harder than (and so could scratch) quartz, which has a rating of 7. But it would be softer than (and could be scratched by) topaz, which has a rating of 8. The scale can be applied to a great variety of materials and was quite the thing for many years. With the invention of various types of testing machines, however, it has become less important.

Sometimes, you will hear a metal referred to as "file hard," which means that it can't be filed away. The basic principle is much the same as that used in Mohs' hardness scale—the ability of a hard substance to scratch or scrape a softer one. You can see that a file of a certain degree of hardness will scratch any softer metal, but, generally speaking, will have no effect on metals harder than it is. From this it is evident that files have a limited use in hardness testing.

In actual practice, three factors govern the use of this method of testing. These are the size, shape, and hardness of files; the speed, pressure, and angle of the file during the test; and the influence of composition and heat treatment on the metal being tested.

The files made especially for hardness testing take care of the first item. The second is controlled to a great extent by the skill and experience of the person

performing the test. Thus, you can file away certain metals by fast, light strokes, where slow, heavy ones will produce little or no effect. Generally, the slower you file the more accurate the test. The third consideration limits even further the range of metal that can be checked by the file method. For instance, steel that has been hardened by heat treatment may resist filing immediately after quenching, but can be filed away quite easily after tempering.

So, DON'T JUMP AT CONCLUSIONS when you see or

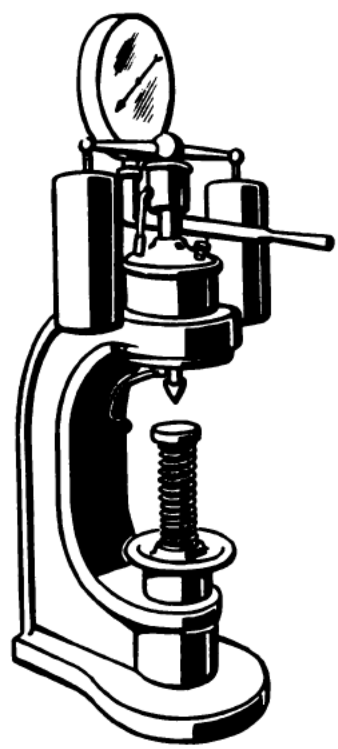


Figure 53.—Brinell hardness tester.

hear the term "file hardness." Think over those three "if's" before you take an option on it. Once you're "in the know" the file method is a rapid, fairly accurate, and economical method of testing or checking the hardness of metal parts.

There are several machines built especially for testing hardness, and you may as well look them over.

The BRINELL machine (figure 53) is designed so that

a fixed load (3,000 kgs) presses a hard steel ball 10 mms in diameter into the object under test. The BRINELL HARDNESS NUMBER is obtained by dividing either the surface area of the impression made by the ball or the diameter of the impression into the amount of load. It is obvious that hard metals will have small

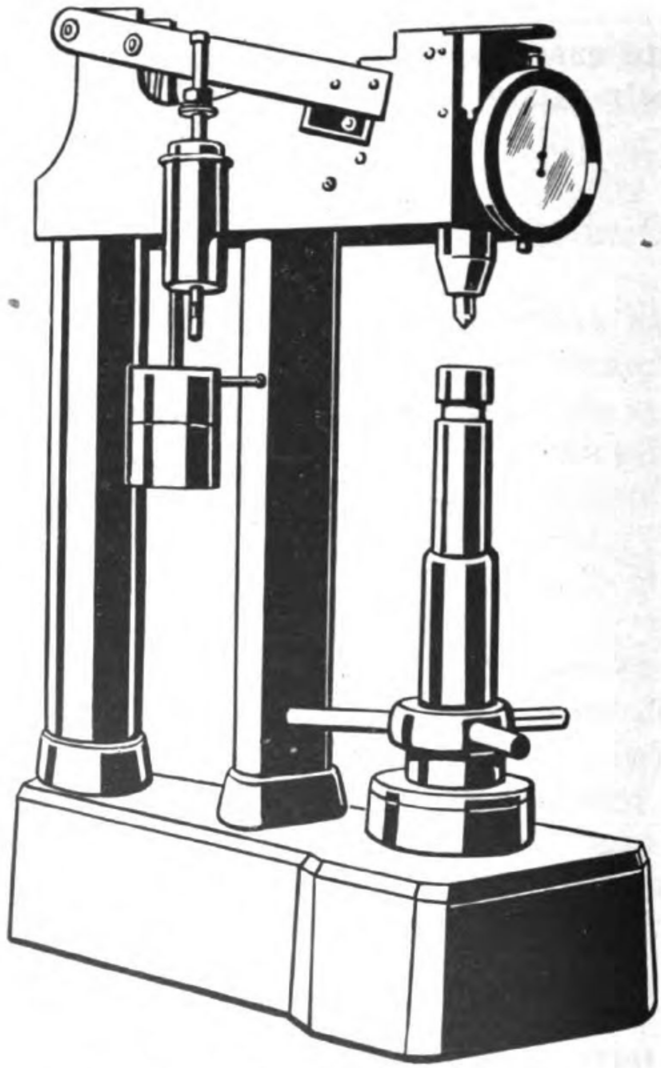


Figure 54.—Rockwell hardness tester.

impressions and large Brinell numbers. The Brinell hardness of annealed copper is about 40, that of annealed tool steel about 200, and that of hardened tool steel about 650.

The Brinell hardness numbers are related closely to

the tensile strength of some types of steel. Therefore, by fairly simple calculation, you can get a reasonably accurate estimate of the tensile strengths of those steels, without going to the trouble of conducting tensile tests. The number used in such calculations is known as a TRANSFERENCE NUMBER. It is secured by correlating the Brinell hardness numbers with corresponding, tested tensile strength values.

The principle of the ROCKWELL method is approximately the same as that of the Brinell test except that it measures the depth of the impression made instead of the diameter. The hardness is shown on a scale attached to the machine, a depth gage graded in special units. The Rockwell method is used generally by aircraft manufacturers because of its direct reading qualities, ease of operation, and reliability. The Rockwell tester is shown in figure 54.

The dial indicator has two scales—the black, or "C" scale, and the red, or "B" scale. The "C" scale is used when testing with a diamond cone and 150-kilogram load, while the "B" scale is used with the steel-ball penetrator and 100-kilogram load. When you record the readings on the scale, prefix them by the letter "B" or "C" to show which scale has been used. When the readings fall below C-20 (B-98), the material is considered too soft for the diamond cone, and you should then use a 1/16-inch hardened ball. Use the diamond cone for all hard materials (those above 100 on the "B" scale) because the steel ball might be deformed by the test.

The SHORE SCLEROSCOPE (figure 55) measures hardness by the height of rebound that a small diamond-tipped hammer makes when dropped upon a specimen from a given height. THE HARDER THE MATERIAL, THE GREATER THE REBOUND. This is a quick and easy method of checking hardness, but your specimens must have a very smooth surface if you are to secure accurate results.

There are other tests for hardness, but those discussed are the ones used most frequently, and the

machines for making them will be found in many of the major overhaul shops. Here again "practice makes per-

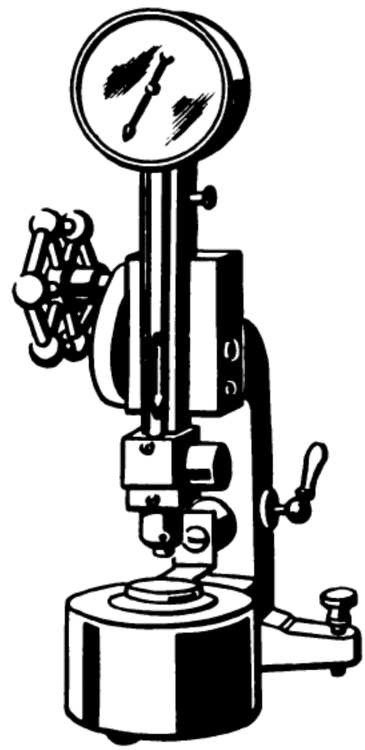


Figure 55.—The Shore scleroscope.

fect." YOU WILL LEARN THE TECHNIQUE OF THE VARIOUS TYPES OF MACHINES ONLY BY OPERATING THEM.

TENSILE, COMPRESSIVE, SHEAR, BEND, AND IMPACT TESTS

As stated before, testing is, in the final analysis, the determination of the strength of materials.

TENSILE TESTS are used to determine the static strength of metals. The usual procedure is to insert a test piece, or test bar, of the metal between the jaws of a suitable testing machine and to increase the load gradually until the metal breaks. The TENSILE STRENGTH thus obtained is the maximum strength of the metal under tension, or the force actually required to pull it apart. Other data recorded during the test are used to compute such factors as yield point, per-

centage of stretch, reduction in cross-sectional area, unit stress, and unit strain.

The accuracy of a tensile test depends upon such factors as the rate at which the load is increased, the way in which your test piece is lined up in the machine, and the type and condition of metal tested. For instance, high strength and brittleness, or brittleness alone, tend to cut down the accuracy of test results, so that, even under the most favorable conditions, you may get differences in load of several thousand of psi with apparently identical samples of metal.

A modified type of tensile test is used to determine the CREEP in metals. This is THE STRETCH IN A PIECE OF METAL THAT IS SUBJECTED TO A CONSTANT LOAD OVER A PERIOD OF TIME. For your information, the degree to which metals will creep under constant load depends upon the amount of load and the time it is applied. This stretch occurs even when the load is light enough so that the stresses imposed are well within the metal's elastic limit. Creep has a temperature hook-up also—the higher the temperature of the metal while under a constant load, the greater the amount of creep. So, creep may be stated in units of elongation (inches of stretch per inch) per unit of load (psi) per unit of time, at a certain temperature. You might state a CREEP VALUE as 0.001 inch per inch per 1,000 hours at 750° F. under a tensile load of 40,000 psi.

COMPRESSIVE TESTS are carried out in much the same manner as tension tests except, of course, the test metal is squeezed or compressed instead of being pulled or stretched. It is very difficult, and often impossible, to determine the maximum strength of any but the more brittle metals under compressive loading. Most metal test pieces do not break or show any measure of ultimate resistance under such loads. They flatten out instead.

Interplane struts and other parts, where compressive strength must be computed by column formulae, are tested and checked in compression testing machines.

Such parts generally turn aside and buckle under loads that are considerably less than those estimated under conditions of ordinary, straight compressive loading.

The strength of materials in SHEAR is computed generally by taking a certain percentage of their tensile strength. For most steels, it is satisfactory to figure on shearing stresses of between 50 and 60 percent of the allowable tensile stresses. You need not depend on such calculations, however, as there are tests by which shearing strength can be determined.

Considerable research has been carried on, in an effort to establish definite values that can be allowed for shearing stresses in aluminum alloy rivets and sheets. You will recall that rivets and metal parts joined by riveting are subjected to shearing stresses when other types of loads, such as tension or compression, are applied. So, if you apply tensile or compressive loads to riveted test assemblies of the proper design, you can compute the approximate shearing strengths of the rivets and of the parts joined by them.

IMPACT is the force with which a moving body strikes against another body, either at rest or moving. THE RESISTANCE OF A METAL TO IMPACT LOADS IS A MEASURE OF THE ENERGY-ABSORBING ABILITY OF THE METAL. This property, incidentally, is sometimes considered as a measure of toughness.

Several methods have been devised to test the resistance of steel to impact loads. The results are of questionable value, but the tests can be used to compare two pieces of material of identical composition and tensile strength. Generally speaking, the tests are run by notching a piece of metal on one side and then fixing it in a machine so that it can be broken by the impact of a falling weight or by a heavily swinging pendulum.

Impact testing is important for aircraft landing gears and parts adjoining them, and you will hear more about the method of testing these assemblies under impact loading later in the chapter.

TESTING ASSEMBLIES IS A COMP

There are many factors to be c
completed aircraft assemblies, point
to assure satisfactory performance
them are:

> Testing to insure the necessa
> Checking of weights, dimensi
> trical bonding, watertightness (h
> and oil tanks, strength and corre
> trols, operation of installed instr
> ment, and the like.

Testing to insure the necessary s
interesting and important to the A
because any repairs or new assem
must be constructed so that they w
strength tests that may be require
The majority of test loads app
assembly are static, or stationary.
placed in service, however, static
either on the ground or in the air.
test loads are generally consid
those actually required for the de
factory static strength. Many o
companies give drop tests to the
This simply means that the planes a
from a previously determined heig
Wings, tail surfaces, fuselages,
assemblies are usually loaded with
with lead shot, or lead bars. Larg
the wings of patrol planes, canno
torily by these methods—their c
that sandbags or similar weights
wings before the desired or require
has been applied. Portable, hydrau
ing machines are used instead. T
cables to the part to be tested aft
mounted on a test block.

Aircraft companies consider wing tests the most critical of all, and during such tests all hands stand with bated breath until they are finished. A wing is loaded past 100 percent of its weight until it buckles and breaks, and WHEN it breaks you know the actual strength of the airplane of which it is a part.

Aircraft landing gears and adjoining parts are tested under impact loads by dropping a properly weighted assembly of landing gear, fuselage, and tail or wheel skids from a given height on them. Testing engineers consider that "drop tests" are THE BEST IN THE BUSINESS for landing gears.

METALLOGRAPHY

METALLOGRAPHY is the study of the internal structure of metals. This subject is usually divided into two stages—the study and application of theories on internal structure, and the examination of metal specimens to check and interpret the basic theories. The second stage, called METALLOGRAPHIC EXAMINATION, is really a phase of inspecting and testing because, in order to be of real value, it must be correlated with the results of chemical examination and of the mechanical properties determined by tests described earlier in the chapter.

Metallographic examination is used to study the structure of metals and to interpret the findings in the light of their chemical composition, previous mechanical treatment, heat treament, and any like factors that may enter in. Cracks, slag inclusions, and other defects may also be detected. Slag can usually be seen with the naked eye. MACROSCOPY is a $50 word for examining specimens with the naked eye, or under very low magnification, but when you have to depend on the microscope, that's MICROSCOPY.

In general, metallographic examination involves the selection or preparation of a metal specimen, its examination either with or without a microscope, and, if necessary, photographing a typical section of the speci-

men. Such photographs, made through a microscope, are known as PHOTOMICROGRAPHS. Large metallurgical microscopes are usually fitted with attachments for taking photomicrographs. In such a machine, the image of the specimen is projected on ground glass at the end of the bellows, just as a camera projects the image of a person onto a ground glass. A photographic plate or film records the magnified image. Objects may be magnified from 10 to 10,000 times. The magnifications used most frequently are 75, 100, 200, and 500, although you will sometimes have to use higher magnifications if you want to see the finer structures.

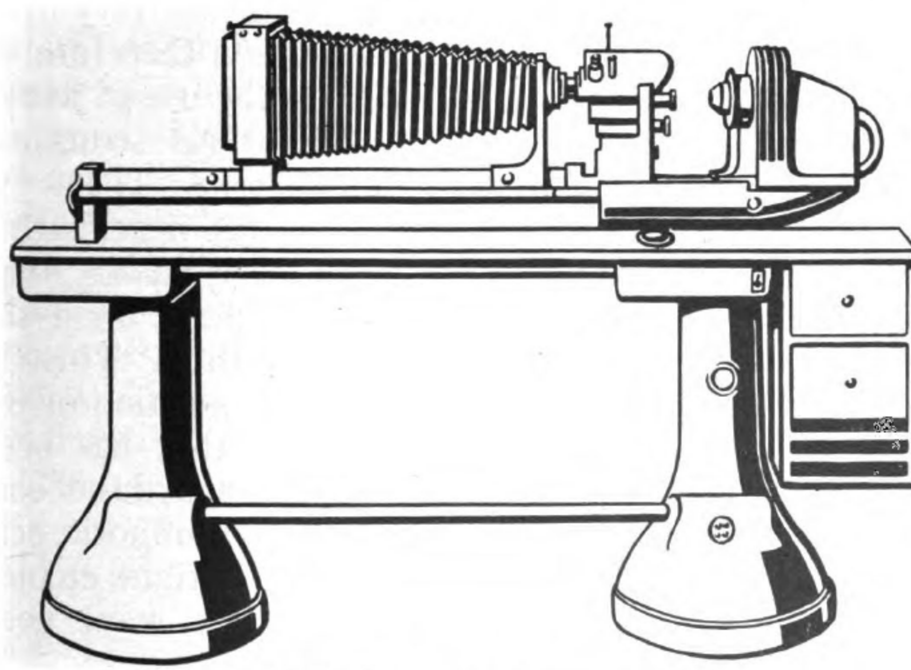


Figure 56.—Photomicroscope.

The type of specimen that you select will depend upon the purpose of examination. Most steel and wrought metal will show different structures when viewed from angles different to the direction in which worked. Thus, looking across the grain, you can see the grain size and the number and distribution of inclusions while a parallel section will show the length of slag inclusions and the influence that working (rolling or forging) has had on

the structure. Specimens of CAST metals can generally be taken from any section, because their internal structure appears the same from any angle.

After you have selected a specimen of the desired size and section, you polish the surface that is to be inspected. The necessarily high finish on the polished surface is secured by some high-geared polishing operations. The kind of abrasives, polishing wheels, and techniques used vary with the kind of metals you are to polish. The ultimate objective of all such operations is to obtain a flat, smooth, clean surface. A properly polished specimen presents a mirrorlike appearance on which foreign matter, slag, cracks, and other defects are detected easily under the microscope, but very little or no structure is evident. It is necessary, therefore, to etch or corrode the surface slightly by the use of ETCHING AGENTS, in order to show the various structural characteristics more clearly.

These agents are usually mild solutions of acids that attack some structures in the metal more rapidly than others. The kind of acid used will depend upon the kinds of structures that are to be studied. This, in turn, will depend upon the chemical composition of the metal and the type of heat treatment that has been used on it. Solutions of nitric or picric acid in alcohol are often used for steel testing, and hydrofluoric acid for aluminum and its alloys. Choose the right etching solution and prepare it properly, if you want good results.

The ordinary laboratory type of microscope is okay for a limited range of metallographic inspection, but special microscopes are manufactured for this work. They provide good illumination, directed on the specimens from above, a special platform or stage on which to place the specimen, and attachments for photographic equipment.

Good equipment plus proper selection and preparation of your specimen plus plenty of knowledge and experience all add up to GOOD PHOTOMICROGRAPHS.

The tests outlined in this chapter fall under the general heads of INSPECTION, TESTING AND METALLOGRAPHY. All three of these procedures are used by manufacturers of aircraft metals, by aircraft companies, and by Army and Navy inspectors of aircraft materials. You too will use some of them—most of them, in fact—if you are assigned to an ASSEMBLY and REPAIR station.

Physical testing is a "must" today. Airplanes are literally built in test tubes—only thus can they be made to withstand the unpredictable. Look at the ads and see the importance that manufacturers attach to testing. "This Typhoon won its wings in a test cell," runs the colorful caption of an airplane engine ad. Leading aircraft instrument makers boast how well their products stand up in "torture machines," and term this endurance "a good sign of how well they'll withstand the abuse of actual Navy service." A manufacturer of landing gear takes the ball and scores a touchdown with the terse statement that his landing gear is tested to withstand any and all types of landings, whether on the windswept steppes of Russia, the scorching sands of North Africa, or emergency landing fields hacked out of the wilderness of a South Pacific island.

He might well have included the rice fields of Japan.

How Well Do You Know—

AIRCRAFT METALS

QUIZ

CHAPTER 1

WHY METALS?

1. (*a*) What type of stress is set up when a pulling, or separating, force is applied?
   (*b*) What is the opposite type of stress? What kind of force is applied?
   (*c*) Whenever a bending stress is set up, it is accompanied by both the above types of stress (*a* and *b* above). Where is each of these two stresses set up, in relation to the place where the force is exerted?
   (*d*) What is the third type of stress included in bending? What part of the airplane carries most of this type?
   (*e*) What is the other type of stress carried by airplane structures? Name an airplane structure where it commonly occurs.
2. (*a*) What two parts are commonly used with thin-walled monocoque structures to prevent wrinkling of the skin?
   (*b*) How do they prevent it?
   (*c*) Why is it so important to prevent it?
3. (*a*) What types of stress do stringers carry?
   (*b*) Why is a fuselage always semi-monocoque, rather than monocoque, if it uses stringers?
4. (*a*) What are the two principal stresses carried by airplane wings?
   (*b*) What causes each of these stresses?
5. (*a*) How many webs does a box wing beam have? What kind of stress do they carry?
   (*b*) Where are the flanges on this kind of wing? What kind of stress do they carry?
6. (*a*) What parts of a multispar wing take the same position as the webs of a box wing beam?
   (*b*) Do these parts carry the same kind of stress the box wing webs carry? Explain your answer.

7. What parts do the ribs brace, and therefore what kind of stress do they help carry, in a box wing beam? In a multi-spar wing?
8. (*a*) What part of an airplane, other than the wing, will act like a beam under bending stress?
   (*b*) What kinds of stress are set up in that part by a vertical bending load? Where are the stresses carried?
   (*c*) Where are those stresses carried, under a horizontal bending load?
9. What causes a torsional load on the fuselage?
10. What 5 factors determine the strength of a strut?

CHAPTER 2

FERROUS METALS

1. What six constituents are usually found in iron ore?
2. What are the three principal forms in which iron is manufactured?
3. What is known as ordinary commercial iron? Describe its characteristics briefly.
4. What kind of cast iron is stronger than ordinary commercial iron but not as strong as steel? What does its name mean?
5. (*a*) What kind of cast iron is so hard that special cutting tools are needed to machine it?
   (*b*) What are its other important characteristics?
   (*c*) How is it used?
6. (*a*) What is the chief purpose of adding nickel to molten gray cast iron? What metals may be added instead of nickel?
   (*b*) What is the resultant metal called?
7. What is the most valuable characteristic of steel as an aircraft metal?
8. Mention a few places where it is used in naval aircraft.

9. (*a*) How many types of steel are used in aircraft work?
   (*b*) Which type is used most?
10. Why is chrome-molybdenum used so widely in aircraft construction?
11. (*a*) A metal used for springs has the SAE number SAE 6150. What does the number mean?
    (*b*) What does SAE 71360 mean?
12. (*a*) What substances other than carbon are found in carbon steel?
    (*b*) Which of these are bad for the steel?
13. What are some qualities of molybdenum steels?
14. (*a*) What is referred to as "18–8"?
    (*b*) What is its main advantage over ordinary steel as an aircraft metal?
    (*c*) What are some of its uses?
15. What is the principal metal in both Monel and Inconel?

CHAPTER 3

NON-FERROUS METALS

1. (*a*) What is aluminum's most important value as an aircraft metal?
   (*b*) What are some of its other advantages?
2. (*a*) How pure is "commercially pure" aluminum?
   (*b*) What are the two general classes of aluminum alloys?
   (*c*) What are some of the uses for aluminum alloys?
3. Match up the symbols at the left with their meanings at the right.

T	Casting alloy, composition modified from the original alloy.
A214	Heat-treated, aged, and strain-hardened.
RT	Heat-treated and fully aged.
½H	Heat-treated but not yet aged.
W	Hard.
H	Half-hard.
S	Wrought alloy.

4. What are the two groups of wrought aluminum alloys?
5. (*a*) What property of copper gives it its greatest value for commercial uses?
   (*b*) In what part of the airplane is copper itself used the most?
6. What determines the grade of phosphor bronze?
7. (*a*) What are some of the uses for beryllium copper in aircraft?
   (*b*) What are some of its valuable features?
8. What quality does magnesium possess in alloy form?
9. Name some of the advantages of magnesium in aircraft.
10. In what forms are magnesium alloys produced?
11. What rivets are recommended for joining magnesium alloy structural sections?

CHAPTER 4

HEAT TREATING

1. What four forms of heat treatment are most used for ferrous metals?
2. What is meant by "critical temperature," with regard to metal?
3. (*a*) At what point in a heat treatment process does steel pick up hardening power?
   (*b*) What temperature will give it its maximum hardness?
4. What makes steel warp and crack during quenching?
5. What is the purpose of brightening the surface of steel during the tempering process?
6. What methods of case hardening are most frequently used?
7. (*a*) What is the purpose of "normalizing"?
   (*b*) What other kind of heat treatment is it classified with?
8. (*a*) What is meant by "packing"?
   (*b*) What is its purpose?

(c) What is another way of achieving this same end?

9. Why are two stages provided for heat treatment of aluminum alloys? What are their names?
10. What two rules must you follow in quenching aluminum alloy after heat treatment in order to preserve its corrosion resistance?
11. What are aluminum alloys heated in?
13. What step should follow immediately after annealing copper?

CHAPTER 5

WORKING PROCESSES

1. Explain the technical difference between hot working and cold working, and why there is no one temperature which separates them.
2. (a) What are the cold working processes?

   (b) What is their chief advantage over hot working?
3. Name some products made by—

   (a) Cold-rolling.

   (b) Cold-drawing.
4. Describe in detail the cold-drawing process for—

   (a) Wire.

   (b) Seamless steel tubing.
5. What steps precede all cold drawing?
6. What are some hot working processes that are important in aircraft work?
7. (a) What two operations does "forging" include?

   (b) What is the difference between hand forging and drop forging?
8. Mention some aircraft metals which can be successfully drop forged.
9. Are all metals heated before being extruded?

CHAPTER 6

PROTECTION FOR METALS

1. (*a*) Name two kinds of corrosion in metals.
   (*b*) What do powdery blotches on metal indicate?
2. (*a*) Why does the joining of dissimilar metals cause corrosion?
   (*b*) Which of two metals so joined would corrode?
3. What are some methods used for mechanical cleaning of metals?
4. What effect does sandblasting have on aluminum alloy surfaces?
5. What are the common chemical cleaning processes for metals?
6. Why should electro cleaned material be given a protective coating as soon as possible after cleaning?
7. Name some metals which may be protected with zinc chromate primer.
8. How should succeeding layers of metal be applied with a metallizing gun?
9. (*a*) What is the name given the all-purpose rust preventive used for both ferrous and non-ferrous metals?
   (*b*) Which type of this material is used only as a dip?
10. (*a*) What, essentially, is the anodizing process?
    (*b*) What does it do for aluminum and aluminum alloys?
11. Is it necessary to give Alclad a chemical protective treatment? Why or why not?
12. What is sometimes used to supplement chemical protective treatments for magnesium?
13. (*a*) What are the materials most frequently used in electroplating?
    (*b*) What is included in a plating solution?

CHAPTER 7

PHYSICAL TESTING OF AIRCRAFT METALS

1. What three fields of testing are covered by the title of this chapter?
2. What basic properties of a metal can be measured by the tension test?
3. What types of tests are required for these aircraft materials?
   (*a*) Wire. (*c*) Cable.
   (*b*) Tubing. (*d*) Forgings.
4. What four simple tests will help you identify a metal?
5. What two examinations of aircraft metal structure are required by the Navy Department?
6. (*a*) What is the purpose of the magnetic inspection process?
   (*b*) What is another name for it?
   (*c*) Why can't it be used on Monel?
7. What are some metal qualities that are determined by testing methods?
8. What is the difference between "hardness" and "mineralogical hardness" of a metal?
9. What metallic quality is measured by the Mohs scale?
10. (*a*) What do Brinell numbers represent?
    (*b*) How are they determined?
11. How does the Rockwell method differ from the Brinell method?
12. What is a third machine for measuring the same quality the Brinell and Rockwell machines measure?
13. (*a*) What is "creep" in metals?
    (*b*) What four units are included in a measure of creep?
14. What aircraft parts must be impact-tested?
15. What name is given to a photograph made through a microscope?
16. (*a*) What are "etching agents" used for in metallographic examination?
    (*b*) What are some good ones for steel and aluminum?

ANSWERS

CHAPTER 1

WHY METALS?

1. (*a*) Tension.
   (*b*) Compression. A force tending to shorten a rigid member.
   (*c*) Compression is set up on the side nearest the place where the force is exerted, and tension is set up on the side furthest away from that place.
   (*d*) Shear. Skin.
   (*e*) Torsion. Engine mount structure.
2. (*a*) Bulkheads and reinforcing rings.
   (*b*) By receiving the concentrated loads bearing on the skin, and distributing them evenly into the walls.
   (*c*) Because the strength of a monocoque structure depends upon its true cylindrical shape.
3. (*a*) Compression and tension.
   (*b*) Because any structure which uses reinforcing parts to actually help the skin carry the load, rather than simply maintain the true shape of the skin, is considered semi-monocoque.
4. (*a*) Bending and torsion.
   (*b*) Bending stress is set up by the lift (upward pressure) produced by the action of air on the wing. Torsion is set up by the shifting of the center of pressure on the wings, as well as the raising or lowering of the ailerons, which accompany changes in the airplane's flight attitude.
5. (*a*) Two. Shear.
   (*b*) The top and bottom surfaces of the wing are the flanges. Tension and compression.
6. (*a*) Spars.
   (*b*) No. They carry tension and compression, like the flanges of the box wing beam.

7. Flanges. Tension and compression.
   Skin and spars. Shear.
8. (*a*) Semi-monocoque fuselage.
   (*b*) Tension on the top of the fuselage (upper stringers), compression on the bottom (lower stringers), and shear on the sides.
   (*c*) Tension on one side of the fuselage, compression on the other side, and shear on the top and bottom.
9. The tendency of the fuselage to turn in a direction opposite to the direction of propeller rotation.
10. Rigid fixing of ends.
    Rigid bracing of middle.
    Stiffness of material (elastic limit).
    Diameter.
    Absence of free edges.

CHAPTER 2

FERROUS METALS

1. Carbon.
   Manganese.
   Silicon.
   Phosphorus.
   Sulfur.
   Oxygen.
2. Cast iron.
   Wrought iron.
   Steel.
3. Gray cast iron.
   Good machinability; high compression value; low tensile strength; no ductility.
4. Malleable cast iron. "Malleable" means capable of being shaped by beating (with a hammer) or rolling.
5. (*a*) White cast iron.

(*b*) Strength and brittleness.

(*c*) It is used for parts that get considerable wear but no direct stress, and for malleable castings.

6. (*a*) To strengthen the iron. Chromium, molybdenum.

   (*b*) Alloy cast iron.

7. Strength.

8. Fuselages.
   Landing gear axles.
   Engine mounts.
   Fittings.

9. (*a*) Two.

   (*b*) Alloy steel.

10. Because it lends itself well to welding, forging, and heat treatment, and is available in many forms.

11. (*a*) SAE 6 1 50

    Approximately 5/100 percent carbon.
    Approximately 1 percent chromium.
    Chrome-vanadium steel.
    Indexed by Society of Automotive Engineers.

    (*b*) SAE7 13 60

    Approximately 60/100 percent carbon.
    Approximately 13 percent tungsten.
    Tungsten steel.

12. (*a*) Manganese.
    Silicon.
    Sulphur.
    Phosphorus.

    (*b*) Sulphur.
    Phosphorus.

13. Toughness.
    Wear-resistance.
    Can be hardened by heat treatment.
    Can be welded.

14. (*a*) Stainless steel.
    (*b*) High corrosion resistance.
    (*c*) Exhaust stacks, manifolds, collector rings.
15. Nickel.

CHAPTER 3

NON-FERROUS METALS

1. (*a*) Light weight.
   (*b*) High corrosion resistance.
   Ease of fabrication.
2. (*a*) At least 99 percent pure.
   (*b*) Wrought alloys.
   Casting alloys.
   (*c*) Wrought alloys are used for stringers, bulkheads, skin, rivets, and extruded sections. Cast alloys are used for fittings, cylinder heads, and pistons.
3. T Heat-treated and fully aged.
   A214 Casting alloy, composition modified from the original alloy.
   RT Heat-treated, aged and strain-hardened.
   ½H Half-hard.
   W Heat-treated but not yet aged.
   H Hard.
   S Wrought alloy.
4. Heat treatable.
   Non-heat treatable.
5. (*a*) Electrical conductivity.
   (*b*) Power plant.
6. The percentage of tin alloy.
7. (*a*) For diaphragms, precision bearings, bushings, ball cages, watch and instrument parts, small machined parts.

(*b*) It can be worked and formed readily, when annealed.
Its physical properties can be improved by heat treatment.
It is highly fatigue- and wear-resistant.
It is highly corrosion-resistant.

8. The highest strength-weight ratio of any commonly used metal.
9. Strength.
Non-magnetic.
Machinability.
Can be welded without difficulty.
10. Castings.
Forgings.
Extrusions.
Rolled sheets.
Plates.
11. 56S aluminum alloy.

CHAPTER 4

HEAT TREATING

1. Annealing.
Normalizing.
Hardening.
Tempering.
2. The temperature at which the grain structure of the metal will change.
3. (*a*) While it is passing through its critical temperature range.
(*b*) 25° to 50° above its upper critical temperature.
4. Certain parts cooling more rapidly than others.
5. To brighten the metal surface so that the tempering colors can be observed as an approximate temperature gage.
6. Carburizing.
Nitriding.
Cyaniding.

7. (*a*) To remove strains caused by machining, forging, bending and welding.

   (*b*) Annealing.

8. (*a*) Burying a hot metal part in some substance having low heat-conductivity.

   (*b*) To cool the metal slowly, as required in the annealing process.

   (*c*) Furnace cooling.

9. Some alloys do not develop their full strength after the first stage. Precipitation and solution.

10. Transfer it from heat source to quench tank QUICKLY.
    Keep quench-water below 50° F.

11. Air furnace or molten salt bath.

12. Cleaning by pickling.

CHAPTER 5

WORKING PROCESSES

1. "Hot working" refers to mechanical working processes performed while the metal is ABOVE its critical range, while "cold working" refers to all such operations performed with the metal BELOW its critical range. There is no single temperature dividing line because the critical range varies with different metals.

2. (*a*) Cold-rolling and cold-drawing.

   (*b*) They yield products with good surface finish and accurate dimensions, whereas hot-worked material lacks both of these properties.

3. (*a*) Sheet stock.
   Bars.

   (*b*) Seamless tubing.
   Streamline tie rods.

4. Check your answers against—
   (*a*) Pages 84 and 85.
   (*b*) Page 86.
5. Pickling.
6. Rolling, forging, pressing, extruding.
7. (*a*) Hand hammering and drop forging.
   (*b*) Hand forging is done with hand hammers, while drop forging is done with a machine.
8. Chrome-molybdenum steel.
   Chrome-nickel-molybdenum steel.
   Aluminum alloys:
   17ST
   25ST.
   A51ST.
9. No.

CHAPTER 6

PROTECTION FOR METALS

1. (*a*) Surface and inter-crystalline.
   (*b*) Surface corrosion.
2. (*a*) Electrolytic action.
   (*b*) The one with the higher electropotential.
3. Sandblasting.
   Scraping.
   Filing.
   Buffing.
   Polishing.
4. It increases their softness and thinness, and decreases their ductility.
5. Organic solvents.
   Pickling.
   Electro cleaning.
6. Foreign materials and new oxides will form on the surface.

7. Aluminum and its alloys.
8. At right angles to the previous layer.
9. (*a*) Paralketone.
   (*b*) Type II.
10. (*a*) Passing an electric current through a metal part while the part is suspended in a chromic acid solution.
    (*b*) It lays a thin film of aluminum oxide on the surface of the metal. This film serves as protection against corrosion and as a paint base.
11. No. Alclad has a surface coating of pure aluminum which resists corrosion.
12. Paint.
13. (*a*) Zinc.
    Cadmium.
    Nickel.
    Chromium.
    (*b*) Salts of the metal to be plated.
    Conductor agent.
    Brightener.

CHAPTER 7

PHYSICAL TESTING OF AIRCRAFT METALS

1. Inspection.
   Testing.
   Metallography.
2. Ultimate tensile strength.
   Yield strength.
   Elongation and reduction of area.
3. (*a*) Bending test.
   Torsion test.
   (*b*) Flattening test.
   (*c*) Bending test.
   Fatigue test.

(*d*) Macro-etch test.
Shear inspection.
Magnaflux examination.
Microscopic examination.

4. Appearance (fractured).
Chip test.
Spark test.
Oxy-acetylene torch test ("blowpipe test").

5. Examination for stress.
Examination for grain direction and fiber structure.

6. (*a*) To detect cracks in material.
(*b*) Magnaflux.
(*c*) Because Monel is nonmagnetic, and this process is based on the magnetization of the material to be tested.

7. Hardness.
Ductility.
Elasticity.
Tensile strength.
Compressive strength.
Shearing strength.

8. "Hardness" refers to the general ability of a material to resist penetration, whereas "mineralogical hardness' refers to the resistance offered by a smooth surface to abrasion.

9. Hardness.

10. (*a*) Hardness.
(*b*) The Brinell machine operates at a fixed load to press a hard steel ball of known diameter into the object under test. The Brinell number is obtained by dividing the amount of load by the surface area (or the diameter) of the ball's impression in the metal.

11. It measures the depth, rather than the diameter, of the impression made; and the Rockwell number is read directly from a scale attached to the machine.

12. Shore Scleroscope.

13. (*a*) The stretch in a piece of metal that is subjected to a constant load over a period of time.

(*b*) Elongation (inches of stretch per inch).
Load (psi).
Time.
Temperature.

14. Landing gears and parts adjoining them.
15. Photomicrograph.
16. (*a*) To corrode polished surfaces enough to make the structural characteristics visible.
    (*b*) Steel: Solutions of nitric or picric acid in alcohol.
    Aluminum: Hydrofluoric acid.

☆ U. S. GOVERNMENT PRINTING OFFICE: 1945—658122—26